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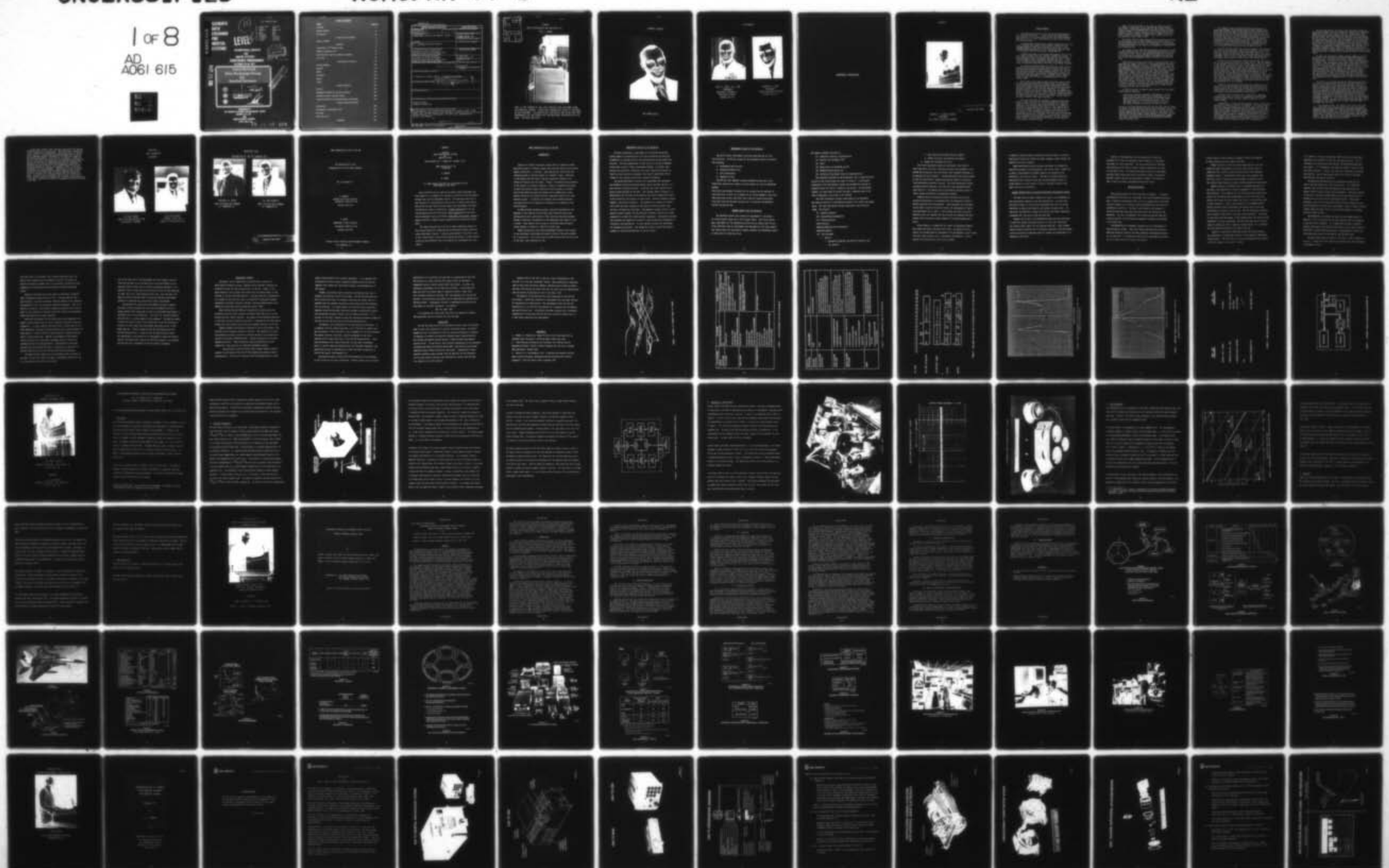

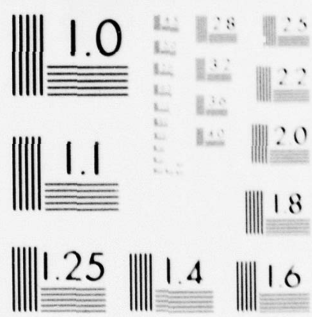


MICROCOPY RESOLUTION TEST CHART

# ELEVENTH DATA EXCHANGE FOR INERTIAL SYSTEMS

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LEVEL II

1977 PLANNING GROUP

| | | |
|---|---|---|
| E. | Bodem, Chmn | Air Force |
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| P. | Zagone | Air Force |



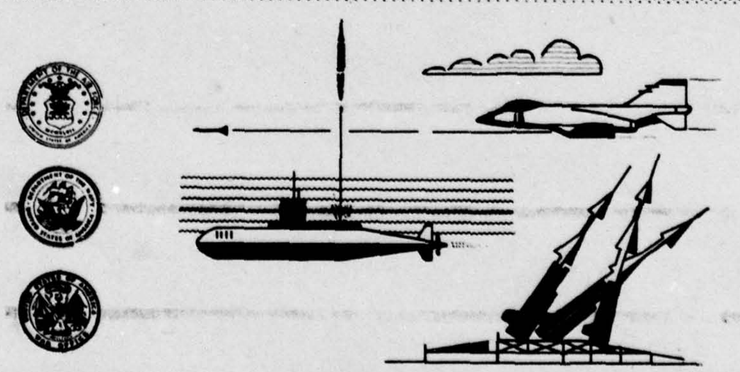
## 'INTERNATIONAL LOGISTICS FOR INERTIAL SYSTEMS'

## CONFERENCE PROCEEDINGS

OCTOBER 26-28, 1977



## Joint Services Data Exchange Group for Inertial Systems





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Conference Proceedings

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The proceedings of the Eleventh Data Exchange for Inertial Systems, 26-28 October 1977, include technical notes and texts of briefings given in the areas of New Technology, Test and Support, Life Cycle Cost, Standardization, Bearings, and Software.

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THESE PROCEEDINGS ARE DEDICATED TO

EARL T. BODEM

EARL IS THE FOUNDER OF THE JOINT SERVICES DATA EXCHANGE GROUP FOR INERTIAL SYSTEMS. AFTER NINE CONSECUTIVE YEARS AS CHAIRMAN HE HAS RESIGNED. HIS DEDICATION, INITIATIVE AND DRIVE HAVE BEEN RESPONSIBLE FOR THE GROWTH AND INTERNATIONAL RECOGNITION OF THE JSDE. WE SHALL MISS HIM.

BANQUET SPEAKER

RAY MONSALVATGE

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CONFERENCE PROCEEDINGS

KEYNOTER

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GENERAL F. MICHAEL ROGERS
COMMANDER
AIR FORCE LOGISTICS COMMAND

## KEYNOTE ADDRESS

I am pleased to be here to kick off the eleventh meeting of this important conference. I correct myself and congratulate the architects of this yearly event of the title "Data Exchange"; that phrase truly is more representative of the kind of results they had envisioned.

I am especially pleased to see so many representatives of our sister services and so many allied visitors. After all, the ultimate purpose of this yearly meeting is more than a strong inertial repair capability, it is to improve the defense of the United States and of the free world. We welcome you.

I should like today to talk about some subjects that are not only close to you who work with inertial systems and avionics every day, but close to us who must deal with all those kinds of defense elements, their management, and what they cost. I hope I can convince you that what you are doing in exchanges such as these is affected by and affects the rest of the defense spectrum.

The factor that distinguishes your field so vividly is cost. Complex, delicate inertial systems are the single, most costly logistical area outside aircraft engines. Not only are they the most difficult systems in which to diagnose fault, but, as you already know too well, consequently are expensive to repair and need costly test equipment. In fact, overall avionics support costs, on some older aircraft, are approaching 75% of total support costs!

From a time in the twenties when air service pilots relied on huge, white painted arrows on hangar roofs to guide them to their destinations, we have arrived at the day when navigation accuracies of one nautical mile per hour are routine with today's inertial navigators. That the word "precision" is nowadays a household word is fitting as we move ahead into the twenty-first century, sub-molecular world. Today's inertial navigation developments are a part of a new industrial revolution, developing side by side with microbiology and the "mini-atom." We are truly in the age of "quarks" and "charm" behavior.

Since we established the Aerospace Guidance and Metrology Center in 1962, the inertial revolution specifically and the avionics field in general have grown phenomenally. Among our 9,000 plus aircraft and 3,000 or more missiles, we maintain an inventory of about 200,000 "black boxes." That doesn't even count around 60,000 allocated to spares and war reserve stocks--all in all, a total investment of around 12 billion dollars. Ten percent of all Air Force RDT&E funds each year go to upgrade, replace and improve this inventory. As you may have read in one of your handouts, the total DOD inventory of inertial systems totals nearly 3 billion dollars--one quarter of the total Air Force avionics inventory value!

AGMC, the largest center of its kind, has seen its share of that number. Since 1962, it has repaired over 70,000 inertial systems and 15,000 displacement gyros--a yearly repaired inventory value of around 1.3 billion dollars--that is 83% of the Air Force inventory! With a capital investment of only around 140 million dollars, AGMC still manages to repair these systems at just over four percent of their dollar value.

My concern with all these figures--and I'm sure yours--is that inertial repair, like the entire inertial and avionics industry, has grown substantially in the last fifteen years. Unfortunately, as with most things, it has grown in an atmosphere of reduced funds and increasing costs.

For example, since 1968, DOD procurement buying power has gone from 44 billion dollars in FY 76 constant dollar outlays to around 17 billion in 1975. Add to that decreasing graph the rising one of inflation and increased performance requirements and you have the all-to-familiar management problem of having to do more with less.

Complicating an already grim picture is the ubiquitous rise in operating and support costs all of us have experienced--Air Force, Army, Navy and commercial aviation. the O&M budget line item for the Department of Defense, for example, has risen from 23% of the total DOD budget to more than 30% in the last nine years. Here at Newark alone, labor, parts, and utilities costs have soared 110% since 1969. Support costs have and will remain a continual problem for us. What used to amount to about 50% of total system cost ten years ago, now stands at around 60%--in other words, two out of every three dollars we spend on a system go to operating and support costs. Unlike the interest on a house mortgage, that ratio not only does not reverse itself as the system grows older--it tends to increase. When you talk about inertial systems and avionics in general, the often-used yardstick of $1,000 a pound is probably not too far off the mark.

So what do we do? As General Jones recently told the Senate Armed Services Committee:

> "Along with achieving substantial improvements in readiness, minimizing the acquisition and ownership costs of weapons will continue to be one of our principal management challenges for the foreseeable future. This is absolutely essential, if we are to obtain and maintain the forces required at prices we can afford to pay."

As many of you heard General Poe tell you last year, the Air Force has begun its concerted effort against such high support costs with the Air Force Acquisition Logistics Division. Working with the Systems Command, ALD gets into the planning of new systems early, working with Systems Command Program Managers to consider logistic implications of designs and to encourage designing for support. This early, before-the-fact planning can do much to hold down those life-cycle costs.

For example, General Poe mentioned the by-now-famous F-4 radio/seat problem. Early planning back in the F-4 design stage would have eliminated much of the quarter-of-a-million-dollar a-month cost we pay for removing the whole seat to get to one radio. An example of that kind of planning paying off already is the A-10. We tested these costs during a 5,000-hour operational test period. That period ended this past April, and Fairchild's performance exceeded their original predictions by 10%! The reward for the contractor--a 2.6-million-dollar award fee. Consequently, the life cycle support costs for the A-10 should be lower than had we just pressed ahead without such target logistic costs.

Inertial systems, which tend to be more esoteric than the more familiar aircraft components, have similar problems. We have one that has a gyro with external weight adjustment capability. Yet on another system, we must tear down the system, adjust the weights, reassemble, test it, tear it down again, adjust the weights again, reassemble, and on and on as often as the test results demand.

On the C-5, we experienced a problem with the INS that turned out to have nothing to do with the system itself. After we repaired it and shipped it back to the user, we were experiencing zero-timers, on 24% of all depot repairs--that is, the system checked all right at the depot, but when the receiving unit checked it, the unit failed to perform. Short-timers, where some field work was required, were as high as 22%. When we examined the packaging, we found that the unit was developing as high as 18 Gs during shipment. The solution: here it was simple--design a new package. The result was only 9 Gs and that reduced zero-timers to 12% and short-timers to 11%. The repair savings amount to around 10,000 dollars per cycle and 165,000 dollars in six months--so now we're examining the way we package the A-7's KT-73 system.

Similarly, we have found that part of the problem with that same KT-73 unit which tested well at AGMC, but often failed to operate once in the aircraft--was that we were not testing the system under the right environmental conditions--conditions that duplicated the operating embience of the aircraft.

The point here is that the most insignificant--seemingly insignificant--items can result in substantial savings in operating and support costs on these already frightfully costly little systems.

Consequently, no aspect of the operation, repair, shipping and testing of a system is too small to overlook. For example, when the field sends a Minuteman unit for repair, they also send data they have collected on several other key elements of the system--that not only shows us what has failed, but helps us predict what might fail shortly. On the C-5 again, MAC was experiencing an unusually high incidence of condensation and shock in the IMU for that behemoth--the unit was located near the nose cargo door. The solution again turned out to be simple--move the unit behind the cockpit--but the long-run savings will be substantial.

We have done much of this kind of cost reduction through the people here at AGMC, field unit people with inquisitive, imaginative dedication to their jobs, and our own ALD. Significantly, you people have been getting together for nine years to do essentially the same thing. But I don't think the need for this data exchange has ever been more pressing. Not only because of the rising costs of support and operating, but because so many of our friends from other countries are beginning to develop their own inertial repair facilities. Of course, our commitments to our many foreign military customers and cooperative logistics agreements are important to us and General Edwards from my staff will talk more of that during tomorrow's special luncheon program on international logistics. But equally important is lending help to these new ventures into inertial repair..

As more join Switzerland, Sweden, Norway, Germany, and Iran--among others--this exchange will become increasingly important to them as well. You who are new to this complex, expensive job of inertial repair can save a lot of time, error, and growing pains by drawing on the considerable experience of those here from the Army, Navy, Air Force, NASA, and industry who have been at it for a while. The people here at Newark, for example, have over fifteen years experience at inertial repair, and they--as with any new operation--made many of the mistakes you are likely to make, survived many of the same frustrations, and rejoiced at many of the same successes. They are a logical reservoir of lessons learned and hard-earned experience--and they have worked to bring the attendance at this exchange from 48 in 1969 to over 250 this year.

Not only is such allied cooperation important--especially in this era of increased Warsaw Pact forces--but interservicing is another logical way to solve many mutual problems. Not only is Newark contributing by doing repair work on inertial systems and gyros for the Army and Navy, but through the efforts of the Joint Logistics Commanders in <u>all</u> maintenance areas, the services have announced nearly 500 new maintenance interservicing decisions (including 36 new starts) reflecting nearly 45 million dollars additional interservicing and nearly 250 million in single service management assignments. The 36 new starts alone have saved nearly 16 million dollars. The repair of the Navy P3-C gyro here is only one example of this program. Many of these ideas can begin in exchanges like this one.

I was pleased to hear, for example, that an Air Force idea back in the early 70s--a design effort for a new solid stated integrated shaft assembly for airborne navigation computers--has gathered speed and promises to save the Naval Air Systems Command around 70 million dollars over the next ten years. The system, I understand, is already well over the predicted 500 MTBF and going strong. That idea came out of this exchange, and that is the kind of cooperation that can help everyone.

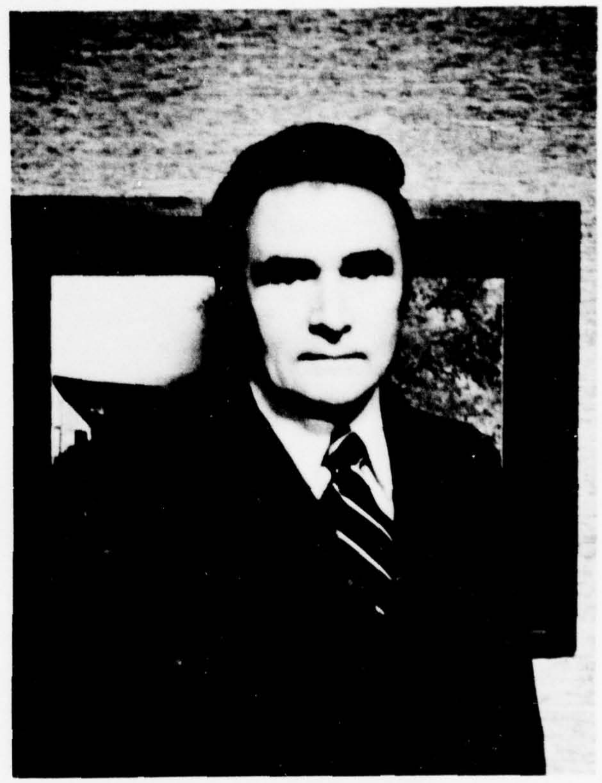
To you "new" people in this delicate, costly world of inertial navigation repair, I wish you luck. More than that, I welcome you to our fifteen years of experience. To you who visit us from our sister services, I encourage even greater cooperation in solving those tremendous monetary challenges to efficient yet economical maintenance and support. To all of you in industry, I thank you for your substantial contributions to our readiness--the industrial base in this country has always been one that has responded when needed with the finest, best-produced equipment in the world. I challenge you now to work with us to achieve that difficult but necessary marriage of quality and reasonable profit at the most economical cost to the taxpayer. Together, we all can do much to strengthen the solid deterrence we have worked so hard to create and prove to our enemies that our Western economic system can produce a stronger, more cohesive defense than any totalitarian state. We can do much in exchanges like this one, in just such quiet, peaceful settings as Newark, Ohio or North Island, California. I wish you a productive and successful exchange over the next two and a half days.

SESSION I

NEW TECHNOLOGY

CHAIRMEN

DR GENE MARNER
ARMY AVIATION RESEARCH AND
DEVELOPMENT COMMAND



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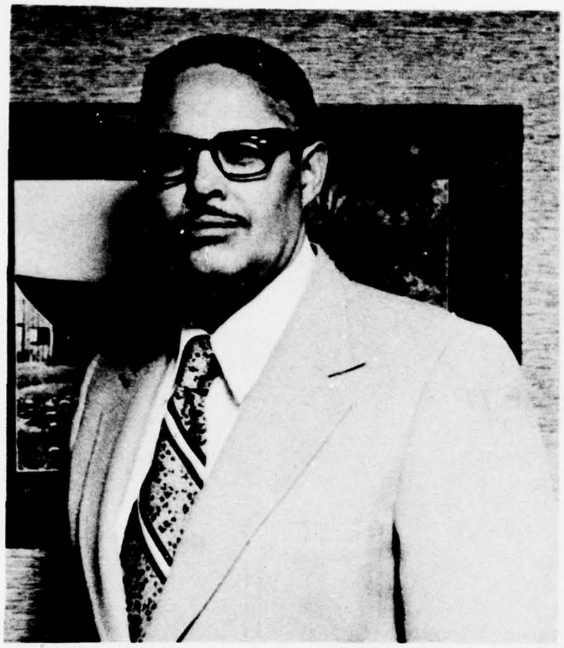
BRIEFING TITLE

INTEGRATION OF THE $F^3$ STANDARD INS



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# ARMY INTEGRATION OF THE F3 STD INS

For Presentation at the

Eleventh Joint Services Data Exchange

26 - 28 October 77

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Navigation Technical Area

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US Army Avionics Research and Development Command

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# ABSTRACT

ELEVENTH
JOINT SERVICES DATA EXCHANGE
FOR
INERTIAL SYSTEM

26-28 OCTOBER 1977 - NEWARK AFS, COLUMBUS, OHIO

## ARMY INTEGRATION OF THE F3 STD INS

J. NIEMELA

R. CREED

U.S. ARMY AVIONICS RESEARCH AND DEVELOPMENT ACTIVITY
FORT MONMOUTH, NEW JERSEY

Due to the high cost of inertial navigation system development and field support it is essential for the Army to satisfy its INS requirements through joint service development efforts. This approach leads also to cost benefits for high production rates as well as shared field support. Once an INS has been identified which meets Army requirements the remaining efforts are those of integration: systems integration of the INS into the appropriate aircraft systems; test integration to avoid duplicative development tests; and finally, procurement and logistics integration to establish a support concept compatible with unique Army requirements.

This paper discusses the first two of these integration aspects of the on going AN/ASN-132 Integrated Inertial Navigation System (IINS) Advanced Development Program. A primary system element of the IINS is the F3 INS. Many aspects of the current program were based on lessons learned during the Army AN/ASN-86 Inertial Navigation Set development and field support.

# ARMY INTEGRATION OF THE F3 STD INS

## INTRODUCTION

Army use of inertial navigation systems (INS) is confined to those applications where a reference system, which provides position and accurate heading information, is required. These applications involve the long standing problem of locating targets at a standoff range. Inaccuracy in the heading reference enters into the system error budget as the product of heading error and range.[1] Figure 1 illustrates these parameters in the context of a tactical situation. Since it is generally desirable to have long standoff ranges, heading error must be kept to a minimum. INS provide heading accuracy much beyond that of magnetically slaved heading references and thereby provide an important capability for Army airborne systems. In addition, INS inherent self-contained non-emitting characteristics are important for operation in a potentially high ECM environment.

An Army airborne navigation system is typically developed for and employed in more than one aircraft type, both fixed and rotary wing. Configuration control particularly of the interface and system software becomes an important consideration in the development and support of such a system. These aspects take on greater significance when navigation system software is unique to a specific aircraft type.

Before discussion of the current development program a brief review of the development, procurement and support history of the Army's AN/ASN-86 is appropriate. This review yields valuable lessons that can be applied to the Army's next generation of INS.

## DEVELOPMENT HISTORY OF THE AN/ASN-86

The Army established a requirement for an Airborne Navigation System capable of performing basic aircraft navigation and providing information to selected avionics and reconnaissance systems aboard the aircraft. This was accomplished in 1967 as part of the OV-1D (Mohawk) Surveillance System's Product Improvement Program. By further integrating the navigation information into other systems with greater reliability than previously obtainable, the overall operational effectiveness of the complete surveillance system was enhanced.

The system developed to satisfy this requirement was designated the AN/ASN-86 Inertial Navigation System, and as the name implies, is a pure inertial navigation system. It was the first pure inertial navigation system employed by the Army. This system, shown in Figure 2, is manufactured for the Army by the Guidance and Control Systems Division of Litton Industries and consists of three units: Inertial Platform, Digital Computer, and Control-Indicator. The Platform is a version of Litton's LN-15 which had been validated at the Central Inertial Guidance Test Facility, Holloman Air Force Base. The Computer includes Litton's LC-728 general purpose computer and the necessary interface circuitry for interconnection to eleven (11) other avionics subsystems. The Control-Indicator Unit provides the capability to enter or read out position information in lat/long or UTM coordinates. It also contains controls for performing all navigation operations. The system has a built in self-test which is capable of isolating malfunctions to the unit level.

## PROCUREMENT HISTORY OF THE AN/ASN-86

The OV-1D Product Improvement previously mentioned was for four OV-1D Aircraft. An RFP was issued for the navigation function including the following:

a. Performance Specification

b. Airborne Navigation Set

c. Full Provisioning

d. Competitive Data

The RFP was later amended to delete Competitive Data and a Firm Fixed Price Contract was issued to Litton Systems for five (5) AN/ASN-86 systems.

Sole source procurements followed for the system which was deployed to South East Asia in April 70 in support of our forces engaged in that area. There have been several additional small quantity system procurements since that time and the Army currently has in inventory 189 AN/ASN-86 Inertial Navigation Sets.

## SUPPORT CONCEPT FOR THE AN/ASN-86

The AN/ASN-86 support was planned and implemented in two phases; an interim support phase and a final support phase. The initial deployment requirement for the AN/ASN-86 occurred with an urgency that did not allow sufficient time for development and deployment of full Army support. The interim phase was developed to support eighteen (18) AN/ASN-86 systems at three sites in South East Asia.

The support elements consisted of:

(1) Contractor technical representatives

(2) Factory Test Equipment (FTE)

(3) Tools

(4) Spare Parts for AN/ASN-86 and FTE

(5) AN/ASN-189 Maintenance Van

(6) Training of Government Technical Representatives

The functions performed by the maintenance vans in South East Asia as part of the interim phase are shown in Figure 3. A preliminary evaluation of this maintenance concept was performed by the Army at Lakehurst Naval Air Station, Lakehurst, New Jersey. The maintenance concept, as established to satisfy the Army's immediate need at the time of deployment, was proven to be feasible.

The final maintenance concept established for the AN/ASN-86 was based on analysis of maintenance personnel skill levels and support costs. The final maintenance concept consisted of the following items. See Figure 4.

(1) Technical Manuals

(2) Provisioning Documentation

(3) Training Courses

Staff Planning

Operator/Organizational Maintenance

DS/GS Maintenance

(4) Test Equipment

a. Special

1. Navigation Computers and Control-Indicator Test Set (NCCITS)

2. Gyro Stabilized Platform Test Set (GSPTS)

3. Module Test Sets, both digital and analog

b. Common Test Equipment and tools

This final maintenance phase was introduced in the 1972-73 time frame which resulted in replacing factory test equipment in the AN/ASM-189 maintenance vans with special test equipment developed to be operated by Army personnel. Trained Army Specialists were assigned to the van installation, thereby reducing the number of contractor field maintenance personnel required. The final maintenance concept included extensive operator use of Built-in Test Equipment (BITE) (See Figure 4). The operator had no maintenance function except to report system performance to maintenance personnel.

Organizational maintenance personnel perform corrective and preventive maintenance in accordance with the appropriate Technical Manuals supplied with the equipment. These personnel also performed visual checks, external continuity checks and replacement of faulty Line Replaceable Units (LRU's). BITE allowed isolation to an LRU; defective LRU's are removed from the aircraft and replaced from maintenance float obtained at Direct Support on a Direct Exchange (DX) basis.

Direct Support is responsible for repair of Navigation Computer Unit (NCU) and Control-Indicator Unit (CIU). The majority of the repairs are accomplished by replacement of faulty modules, circuit cards, and other unserviceable, quick, replaceable subassemblies. Direct Support also provides LRU's for Direct Exchange.

In addition, General Support maintenance performs repairs to the Gyro Stabilized Platform Unit (GSPU) and major component repairs beyond the capability of Direct Support.

Depot maintenance performs Overhaul and Repair of economically repairable equipment including modules, and circuit cards. Items such as gyros, accelerometers and memory modules are returned to the contractor's facility for repair. The Army is currently exploring the possibility of doing its own gyro and accelerometer repair at either Newark Air Force Station in Ohio or the Navy's North Island Repair facility in California.

## LESSONS LEARNED FROM THE AN/ASN-86 DEVELOPMENT/PROCUREMENT/SUPPORT

The Army tried to obtain competitive rights to the AN/ASN-86 but were unsuccessful because of the data package cost. The fact that the Army has been in a sole source procurement position for the AN/ASN-86 has no doubt significantly contributed to program cost. The Army plans to establish a competitive position and remain competitive throughout the life cycle of the next Army INS.

Another cost driver to the AN/ASN-86 program has been the manner in which the systems have been procured; in very small quantities over several years under five (5) separate contracts. Every attempt should be made to procure the full quantity required in one procurement with the inclusion of adequate spares to support the system when it is deployed to the field.

Similar to the AN/ASN-86, the next generation of Army INS equipment will likely be deployed in small numbers at a relatively few number of sites, worldwide. The cost associated with training, provisioning and fielding an organic support organization for such an item may be high. The recently developed reliability improvement warranty (RIW) concept may offer an attractive support alternative. Whatever support concept the Army employs, whether it be organic or RIW, it must be closely coordinated with the Air Force.

## THE NEW REQUIREMENT

The continuing need for INS by the Army is apparent. Initially the AN/ASN-86 satisfied this requirement, the current AN/ASN-132 development is based on established needs, and it is expected that future Army airborne systems will continue to have requirements that only inertial technology can satisfy. The Army is well aware of the advances in inertial technology that have taken place since the fielding of the AN/ASN-86. The cost, maintenance, and reliability benefits made possible by advances in gyro design and computer technology are expected to be significant.

The NAVCON PMO has management responsibility for development of Army navigation systems. They have closely monitored the previously mentioned technical advances and have supported a development approach for a system that is configured to meet current requirements and flexibility to meet future anticipated requirements.

A brief outline of the technical parameters follows with emphasis on those aspects that are unique to the Army.

Though no specific limits have been established for the size, weight and power requirements of the INS, these factors must be compatible with a one-box (inertial measuring unit with computer) packaging concept. Considerations which favor this approach from the Army's point of view are the fewer number of connectors and a less complex mount leading to a more reliable mechanical configuration.

Another technical requirement that is considered mandatory for the Army's next generation of inertial equipment is a MIL-STD-1553A data interface. This standard will not only facilitate configuration control for the system under development, but will facilitate integration with future aircraft systems which use it as the primary means of data transmittal. Data to be provided on this command/response data bus system include conventional INS outputs such as lat/long, true heading, attitude, as well as UTM. The INS system must therefore, have a computer algorithm for lat/long to UTM conversion. The reason for the Army's UTM requirement is that ground forces rely solely on UTM coordinates for their operations, and since most Army aerial missions relate to rendezvous with or support of ground forces, it is essential that this data be provided as an output of the INS.

Figure 5 is the MIL-STD-1553A data format for UTM coordinates. The information is transmitted serially in four twenty-bit Manchester Bi-Phase words. The first word is grid zone designation which defines a $6^{\circ}$ by $8^{\circ}$ segment of the earth's surface.

It is coded in a binary coded decimal (BCD) field for the two numeric characters and one USACS II field for the alpha character. This is followed by the second word which defines the hundred-thousand meter grid square. It is composed of two eight bit USACS II fields for the two alpha characters. Finally, the third and fourth words are easting and northing. Each of these words contain four fields of BCD data providing ten (10) meters resolution.

As previously mentioned this next generation system will be used in both helicopter and fixed wing aircraft. It is therefore essential that the INS system considered for Army application be tested in both fixed and rotary wing environments. Helicopter testing of the INS is routinely accomplished as part of the Central Inertial Guidance Test Facility (CIGTF) Standardized Tests[2]. Army unique maneuvers, such as nap-of-the-earth flight and bob-up maneuvers, and evasive maneuvers can readily be incorporated as part of special analysis flights should the need arise to verify INS performance in simulated tactical flight profiles.

The helicopter environment has proven to be extremely harsh to some INS. This is primarily due to high vibration levels at harmonics of the main rotor frequency. It is noted that the Army's vibration testing requirements are different than that of the Air Force which has found that a random vibration spectrum is representative of their jet and turbo-prop aircraft as discussed at the STD INS forums.

The most widely used helicopter in the Army's current inventory is the UH-1, a single main rotor vehicle with nominal main rotor frequency of 324 RPM or 5.4 Hz.

Since the rotor is two bladed, high vibration amplitude levels are seen at this frequency and its harmonics of 10.8, 21.6, and 43 Hz. Inertial navigation equipment that is not properly isolated for these frequencies can experience high translational vibration amplitude levels.

Figure 6, extracted from a test report on helicopter vibration[3], shows a probability density plot at 11 Hz. The dual peaks of this data indicate a very high sinusoidal vibration content at the frequency corresponding to the 10.8 Hz two-per-revolution frequency. This is in contrast to Figure 7, which shows a probability density plot of 401 Hz which is not a harmonic of the main rotor and is close to the expected normal distribution for random vibration.

Other Army helicopters with different main rotor frequencies and number of rotor blades have, of course, different vibration levels and frequencies. In fact, attention has been given in recent years by airborne developers to decrease vibration levels seen in the helicopter aircrew station. A direct fallout of these efforts is reduced vibration levels in the avionics bay. However, large numbers of helicopters such as the UH-1 are in the Army's inventory and will likely be a candidate vehicle for INS application. Consideration of the above provides the reason behind the Army's insistence for sinusoidal vibration testing as part of the STD INS qualification procedures.

The above briefly summarized INS requirements that are unique to the Army. We will now discuss the Army's development approach for use of a system which meets these requirements.

Due to the high cost of INS development and field support, and the fact that the Army is not currently and is not anticipated to be in the near future a large user of inertial navigation equipment, it is essential that the Army work with the other services to take advantage of lower costs for a high production rate item. Over the years the Army has jointly sponsored both in-house and contractor development efforts for subsystem and system level inertial development.

The approach for system level development has been to examine the other services programs and form joint development efforts on those programs that closely meet current or anticipated requirements in accordance with current DOD policy. The form, fit, function Standard INS (STD INS) is a prime example of this approach. The Army has worked closely with the Air Force in the formulation of the STD INS Characteristics to insure that Army requirements mentioned earlier in this paper were met. Figure 8 compares Army INS requirements with the STD INS Characteristics. Since the STD INS Characteristics meets our requirements, and systems are in development to meet this characteristic, the Army effort required to field this system is to integrate the STD INS with a complement of mission specific equipments.

## DEVELOPMENT APPROACH

The Army's initial application of the STD INS is a part of a multi-sensor navigation system. Updates from an external reference are required to bound the time growing errors of the INS. Figure 9 is a block diagram of this system, which shows that the primary means of data transfer is the MIL-STD-1553A data bus. The Army views this configuration as a system in the classical sense, a collection of subsystems elements integrated to perform a specific function, and have nomenclatured it the AN/ASN-132 Integrated Inertial Navigation System (IINS).

Data from the INS and TACAN are transferred via the mux bus to a navigation processor which executes the update algorithm as well as the primary data bus control function. The output of the navigation processor is the high accuracy navigation data which is displayed on the IINS Control Display Unit and received and utilized by equipment external to the IINS.

Several hardware configuration alternatives exist with regard to the location of the navigation processor function. One approach is to place the navigation processor function in the CDU similar to the system architecture of the Army's AN/ASN-128 LDNS. Another alternative is to have a seperate black box. These alternative system architectures will be traded-off in the course of our advanced development program.

The decision to place the multi-sensor update computer function external to and seperate from the STD INS computer was based on several considerations. The first of these was the F3 philosophy which is aimed

toward interchangeability of avionics equipments. It is apparent that incorporation of multi-sensor navigation software within the STD INS computer could impede the trend toward eventual interchangeability of INS systems.

Another, and perhaps equally important consideration was that of software configuration control by the Army. The STD INS Characteristic has no formal provisions for software configuration control, and it is expected that the computer structures of the several STD INS candidates will be different. For these reasons, the IINS will have a physically separate navigation processor upon which software configuration control, from development through fielding, will be tightly controlled. It is the goal of the Army's program to have this navigation processor compatible with any and all INS which meet the STD INS Characteristics.

The benefits and consequences of this decision were understood. It is apparent that the update algorithms, be it fixed gain or Kalman type, must be general in form such that it can accomodate all STD INS candidates. The update algorithm, therefore, cannot be dependent on the error characteristics beyond that given in the STD INS Characteristic. Since high performance multi-sensor algorithms include state information, which is inertial measuring mechanization and instrument dependent, some penalty may be paid in performance to orient the Army's integration of the STD INS toward interchangeability.

The specific manner in which the UTM information will be displayed to the aircrew has not been established. Several options exist including

modification of an existing F-16 type CDU or incorporation of the IINS CDU function on a multi-function CDU system similar to the Army's Integrated Avionics Control System (IACS) type format. In brief, the techinical requirements for the CDU are as follows. It must have the means by which the systems modes of operation (on/off, align, test, etc.) and data selection (lat/long, UTM, true heading, etc.) can be controlled. The UTM display requirement can be understood by examination of UTM data format. A geographic location is unambiguously defined to ten (10) meters by thirteen characters. For example:

18T WV 1234 1234

It is apparent that more alpha characters are required to display UTM coordinates than are required for only lat/long.

## CONCLUSIONS

The STD INS Characteristic has provided the Army a basis for development of their next generation of inertial navigation system. The Army's AN/ASN-132 IINS is configured so that its system architecture is amenable to advances in inertial and external reference sensor state-of-the-art. Our current development program employs a TACAN to bound time growing position error. In the future, other external references will be considered including the Global Positioning System (GPS), the Position and Location Reporting System (PLRS) and terrain correlation. Integration of these external reference sensor systems into the IINS will be facilitated by the standard digital interface and configuration control that the Army has imposed on the IINS software.

Another asset of the IINS is that by virtue of employment of the STD INS, it is not gyro technology limited. When advanced gyro technology such as Ring Laser and Nuclear Magnetic Resonance Gyros become available - and their anticipated low acquisition and life cycle cost are substantiated - they can readily be employed as part of the Army's IINS.

The benefits of the Army and Air Force cooperation of the STD INS are evident. Significant reduction in development cost have been achieved by incorporation of Army specific INS requirements within the STD INS Characteristics to avoid the requirements for a seperate Army development and qualification test. In addition, the Army currently has a reasonable expectation of having qualified STD INS units available competitively in a time frame compatible with requirements.

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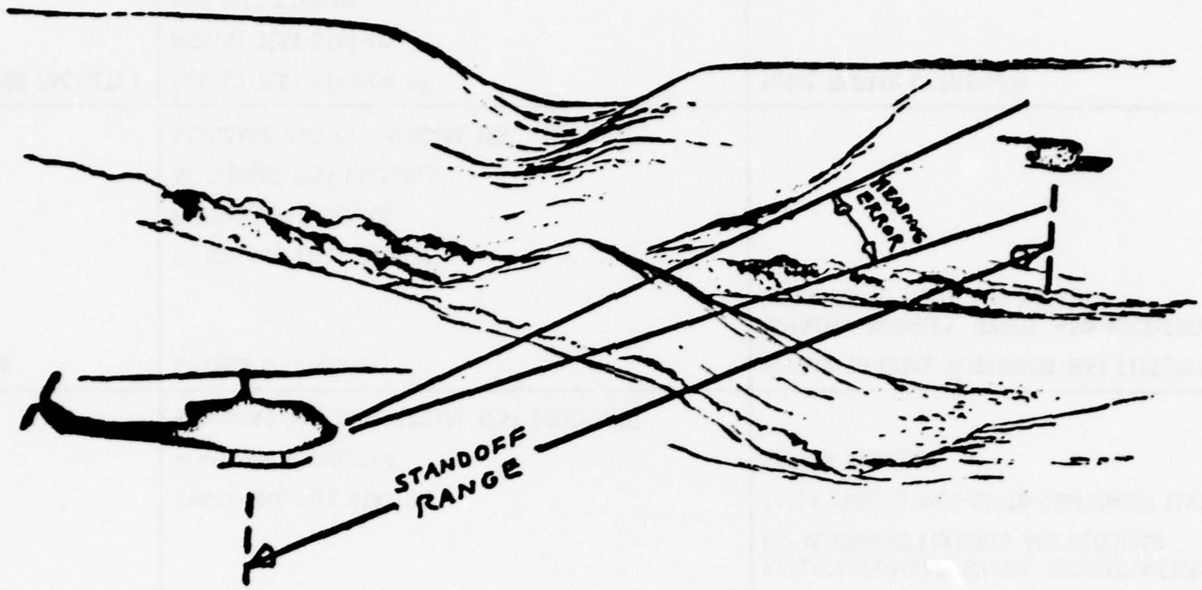



FIGURE 1 AIRCRAFT AT STANDOFF RANGE TO A TARGET

| LEVEL OF MAINTENANCE | TEST EQUIPMENT | MAINTENANCE CONCEPT |
|---|---|---|
| OPERATOR | BUILT-IN TEST EQUIPMENT (BITE) | REPORT SYSTEM PERFORMANCE TO MAINTENANCE PERSONNEL |
| ORGANIZATIONAL | BITE | FAULT ISOLATE TO LRU: REPLACE FAULTY LRU |
| DIRECT SUPPORT | SYSTEM TEST STAND | FAULT ISOLATE LRU TO MODULE, TRAYS, POWER SUPPLIES, ETC. |
| | | REPLACE MODULES, GYROS, ACCELEROMETERS, ETC. WHERE NO ALIGNMENT FIXTURES ARE REQUIRED |
| | PURGE AND FILL STATION | FAULT ISOLATE MODULE TO COMPONENT LEVEL |
| | PLATFORM SIMULATOR | REPAIR MODULES |
| | STANDARD AND COMMERCIAL TEST EQUIPMENT | |
| GENERAL SUPPORT | SYSTEM TEST STAND | REPAIR TO LRU'S REQUIRING TEST FIXTURES |
| | | (MEMORY MODULES, GYROS, AND ACCELEROMETERS WILL BE RETURNED TO DEPOT FOR REPAIR |
| | PURGE AND FILL STATION | |
| | PLATFORM SIMULATOR | |
| | ALIGNMENT TEST FIXTURES | |
| | STANDARD AND COMMERCIAL TEST EQUIPMENT | |
| DEPOT (CONTRACTOR FACILITY) | NCU/CI TEST STATION | TOTAL REPAIR CAPABILITY |
| | MODULE TEST STATION | |
| | IMU TEST STATION | |
| | PRECISION MOUNTING STAND | |
| | PURGE AND FILL STATION | |
| | VARIOUS ELECTRO/MECHANICAL STATIONS AND TOOLS | |
| | STD/COMM TEST EQUIPMENT | |

FIGURE 3 INTERIM MAINTENANCE PLAN FOR THE AN/ASN-86

| LEVELS OF MAINTENANCE | TEST EQUIPMENT | CONCEPT |
|---|---|---|
| OPERATORS (1st Echelon) | • Bite | No maintenance action |
| ORGANIZATIONAL (2nd Echelon) | • Bite | Fault isolate to Platform MX-8123, Control Indicator ID-1579, Navigation Computer CP-941 Repairman will replace unserviceable LRU's and will perform limited replacement of easily removable parts, such as knobs or items not requiring major disassembly. |
| DIRECT SUPPORT (3rd Echelon) | • Computer/Control Indicator Test Set<br>• Standard/Common Test Equipment<br>• Special Tools | Fault Isolate NCU and CIU to Modules (Trays, Power Supplies, etc.). Repairman will troubleshoot and perform replacement of unserviceable items for return to user. Will evacuate items requiring repair to General Support. |
| GENERAL SUPPORT (4th Echelon) | • Computer/Control Indicator Test Set<br>• Platform Test Set<br>• Precision Mounting Stand<br>• Purge & Fill Station<br>• Standard/Common Test Equipment<br>Special Tools | Fault Isolate GSPU to Modules (Gyros, Accelerometers, Power Supplies, etc.). Repairman will repair items and perform more difficult maintenance tasks than DS. Will evacuate all modules and other items not repairable at that station to the Depot. |
| DEPOT | • Module Test Set<br>• Various Electronic Test Stations and Tools<br>• Various Electro/Mechanical Test Stations and Tools | Fault Isolate Modules to Component Part Level. Total Item Repair & Overhaul to restore an item to serviceable condition and return to Depot stock. |

FIGURE 4 FINAL MAINTENANCE PLAN FOR THE AN/ASN-86

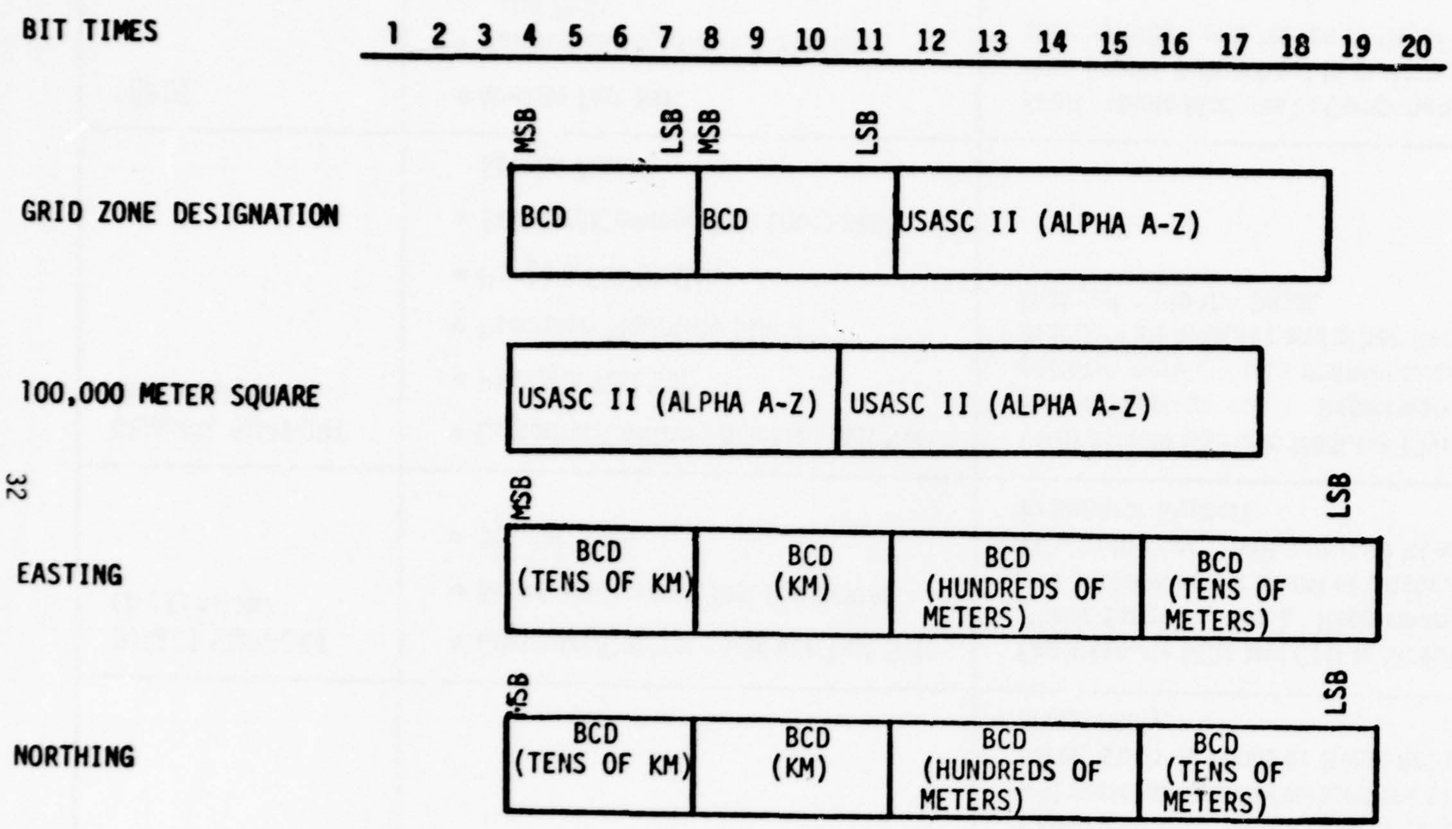



FIGURE 5 DATA WORD STRUCTURE FOR UTM COORDINATES ON MIL-STD-1553A DATA BUS

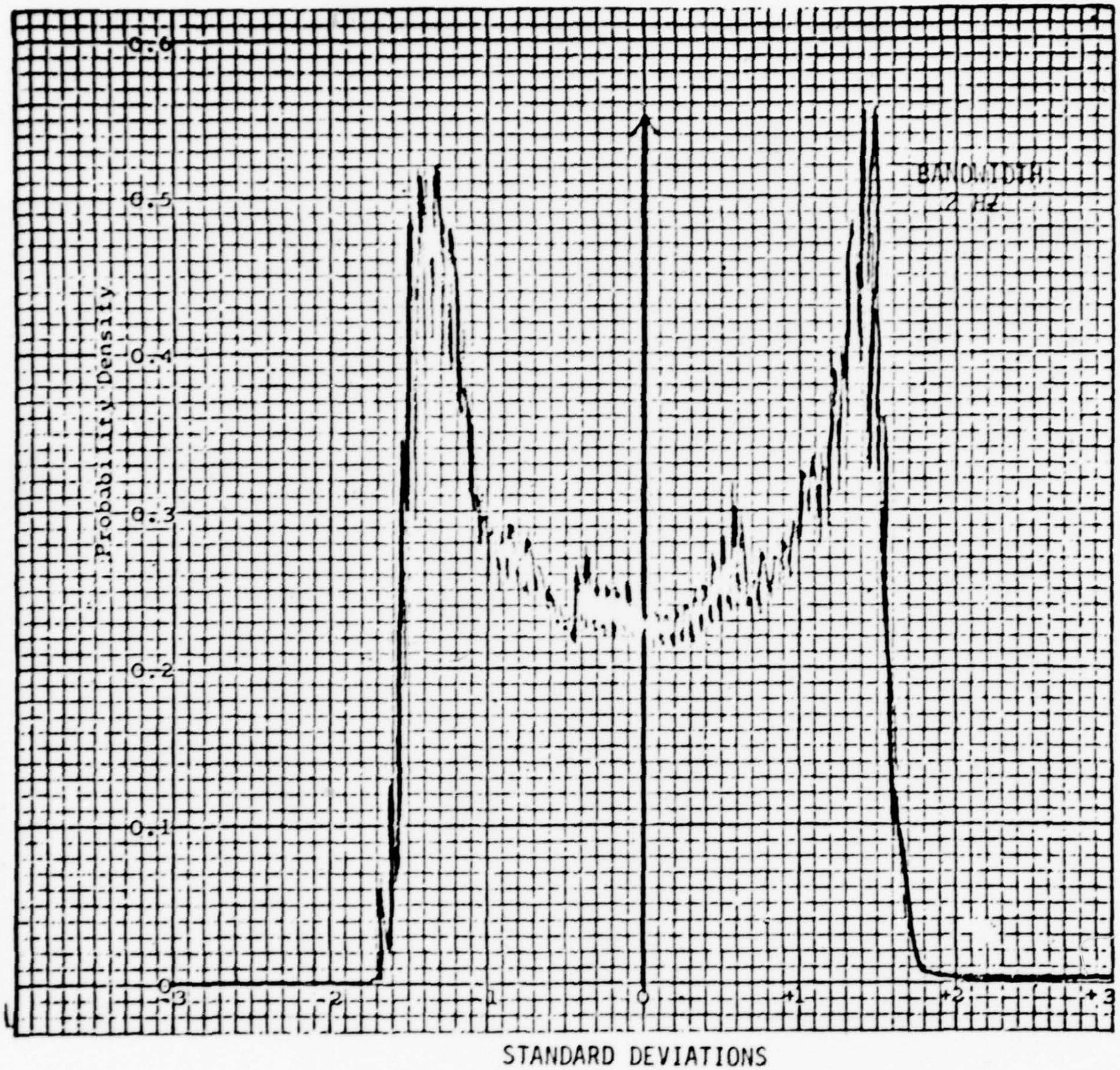



FIGURE 6 AMPLITUDE PROBABILITY DENSITY FOR UH-1 AT 11 HZ
(EXTRACTED FROM REFERENCE 3)

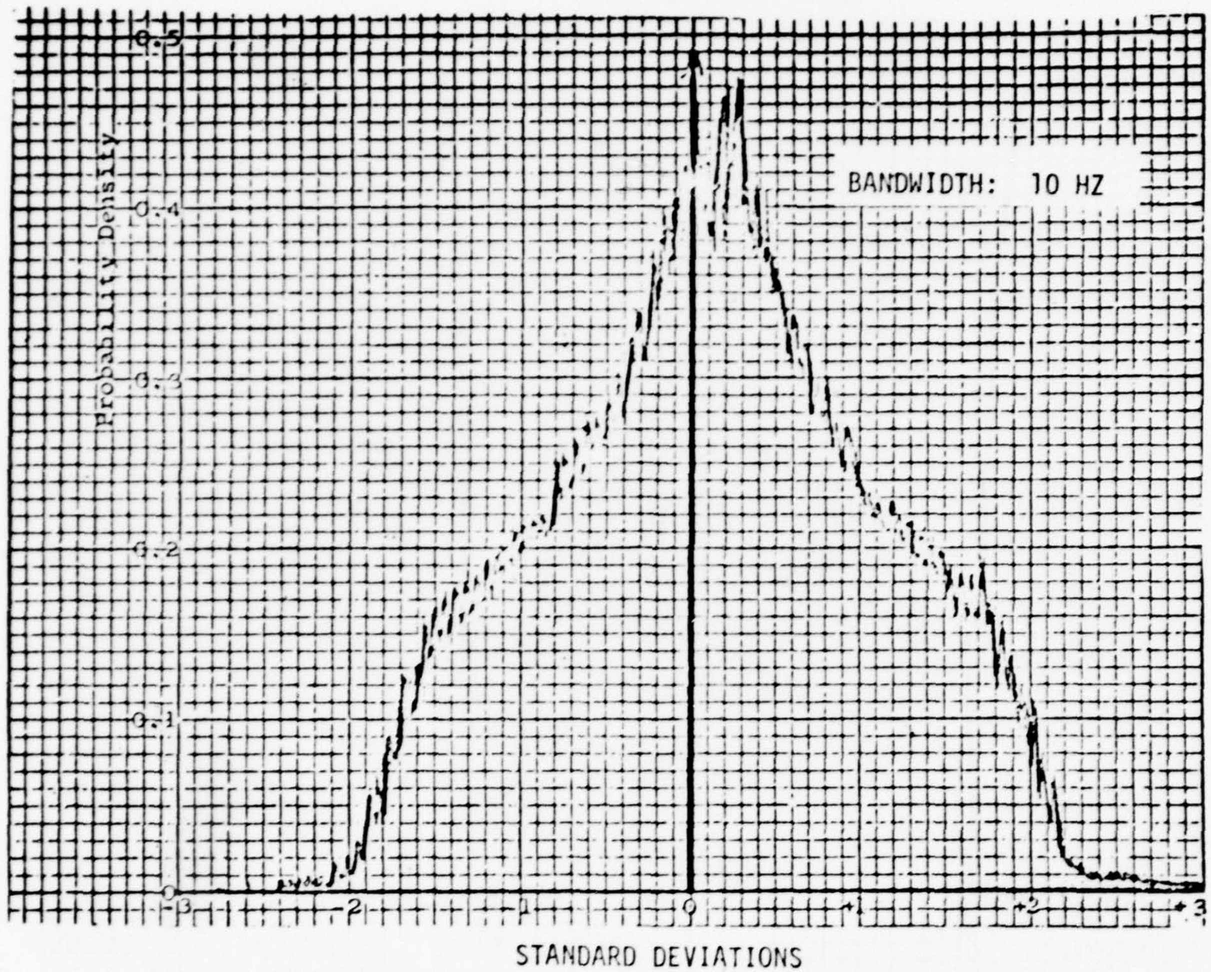



**FIGURE 7 AMPLITUDE PROBABILITY DENSITY FOR UH-1 AT 401 HZ.**

(EXTRACTED FROM REFERENCE 3)

| ARMY INS REQUIREMENTS | STD INS CHARACTERISTICS |
|---|---|
| APPROX. ONE (1) NMI/H | 0.8 NMI/H |
| IMPROVED SIZE, WT., PWR. | 3/4 ATR; 40 LBS; 1700 W START, 340 W RUN |
| STANDARD DIGITAL INTERFACE | MIL-STD-1553A |
| UTM | ✓ |
| SINUSOIDAL VIBRATION TEST | MIL-STD-810C, LEVEL M |

FIGURE 8 ARMY REQUIREMENTS VERSUS STD INS

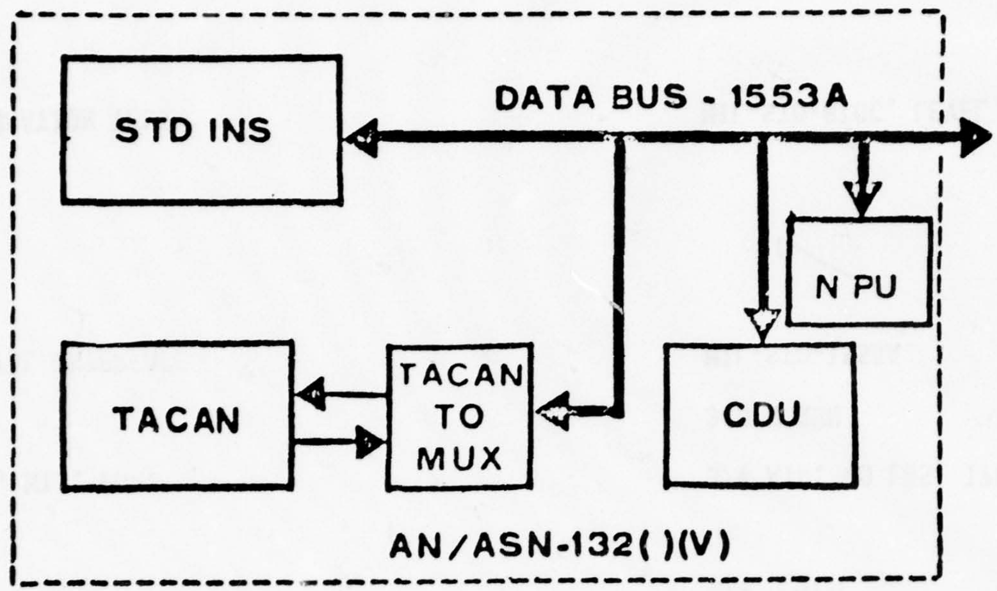
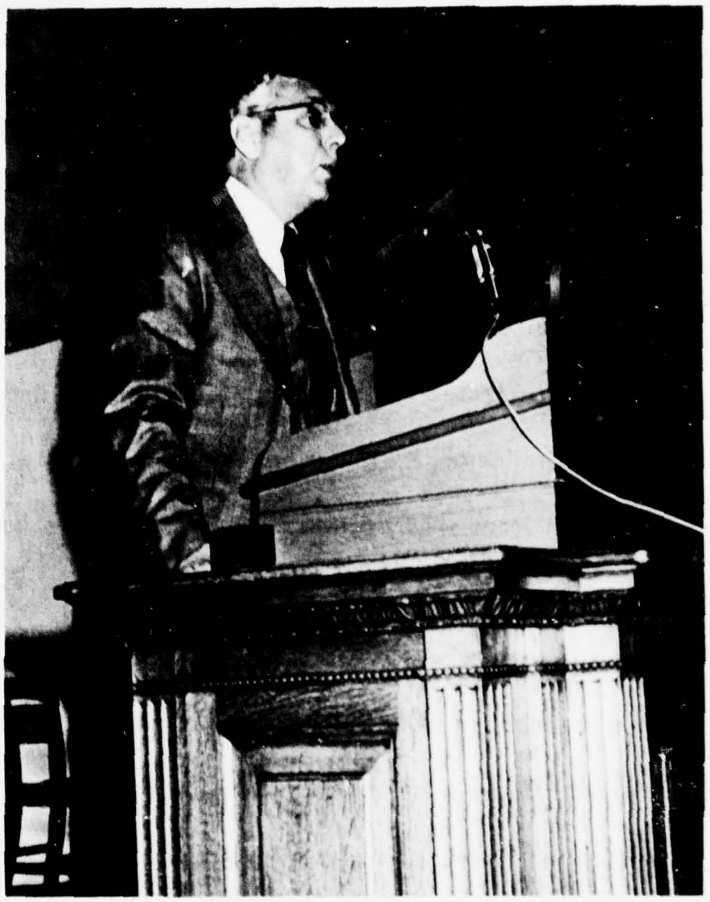



FIGURE 9 INTEGRATED INERTIAL NAVIGATION SYSTEM AN/ASN-132

BRIEFING TITLE

MAGNETIC RESONANCE GYRO



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# THE MAGNETIC RESONANCE GYROSCOPE FOR STRAPPED DOWN SYSTEMS*

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To be presented at Eleventh Data Exchange for Inertial Systems, Newark, Ohio, Oct.26-28, 1977

## 1. Introduction

The extreme environmental conditions, high rates, and absence of error cancellation to which an inertial instrument is subjected in the strapped down mode imposes increased performance requirements such as dynamic range, linearity, and bias stability. In addition, these instruments not only must meet these performance specifications but also have low cost and be easy to maintain. Several candidates for gyroscopic sensors have appeared in recent years. The magnetic resonance gyroscope (MRG) is one of these. It is a gyro that has no rotating or vibrating mechanical parts. The MRG obtains its rotation information from the dynamic angular motion of the nuclei of a collection of atoms in the vapor state. An MRG is a rate-integrating single-axis gyro; its output is the angle of rotation about the sensitive axis.

A mock-up of a planned model of an MRG is shown in the first slide. This model was designed to illustrate general size and optimum arrangement of components based upon calculated and experimentally observed parameters. The model also illustrates the modular construction which lends itself to ease of repair.

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Singer-Kearfott's Research Center recognizes that Logistics support can account for a large percentage of overall life cycle costs and has emphasized maintainability features early in design and development. We feel that the maintenance characteristics associated with this particular technology will contribute to the inertial community's objectives of low acquisition cost and minimum cost of ownership.

## 2. Principles of Operation

The basic sensor of the gyro is the mercury cell, a fused quartz container, evacuated and then filled with a very low pressure of mercury vapor enriched in the stable odd isotopes $^{199}Hg$ and $^{201}Hg$. In Figure 1, the cell holder with a cell in it and the lamp holder have been removed from the unit. When the cell holder is in place the mercury cell is located at the center of the magnetic field coil structure at the intersection of two light beams, the pump beam and the readout beam. The pump beam is a circularly polarized beam with a wavelength of 253.7nm. On interacting with the mercury atoms it orients the nuclei of the mercury atoms, establishing a net nuclear magnetic moment along the direction of the magnetic field established by the coil structure. This interaction is called optical pumping. The nuclear magnetizations for $^{199}Hg$ and $^{201}Hg$ are driven in precession about the direction of the dc magnetic field, $H_o$, at their resonance frequencies which are proportional to the magnitude of $H_o$. This technique is one of the well known methods of nuclear magnetic resonance. In current models of the gyro, $H_o$ is 1.32 oersted, a little more than twice the value of the earth's magnetic field. This places the magnetic resonance frequencies for $^{199}Hg$ and $^{201}Hg$ at 1kHz and 369Hz, respectively. The motions of the mercury magnetizations

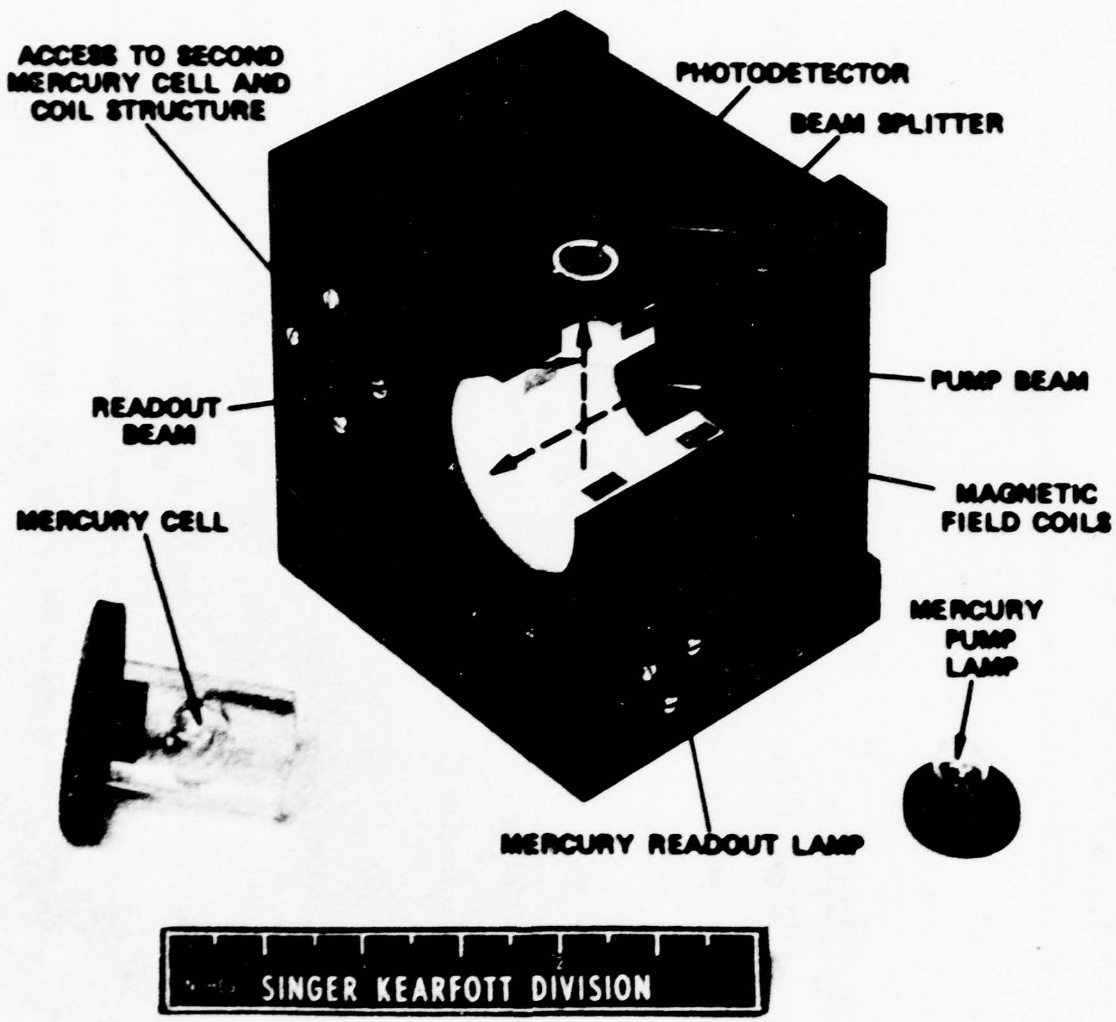


FIGURE 1. MOCK UP OF FUTURE MODEL OF MRG

are monitored by means of the readout beam which is slightly off resonance with the optical absorption frequency of the atoms in the cell and linearly polarized. On interacting with the mercury atoms in the cell the angle of the plane of polarization of the readout beam is modulated at both the resonance frequencies. This interaction is called the transverse rf Faraday effect. The modulation in angle is easily converted to amplitude modulation by means of a suitably oriented analyzer, and the amplitude modulation of the beam is detected by the photodetector. The electrical signals from the photodetector are amplified and fed back to drive the resonances through another pair of coils mounted with their axis perpendicular to $H_o$. These coils for generating the $H_1$ fields are not visible in Figure 1. This electro-optical assembly is a magnetic-resonance-controlled oscillator that runs simultaneously at both 1kHz and 369Hz. It is also called a spin generator.

Comparison of the phases of the mercury magnetic resonance signals provides the information for measuring rotation angles. Proportionality between nuclear magnetic resonance frequency and magnetic field holds only in a non-rotating framework. If the magnetic resonance apparatus rotates with a component of rotation along the $H_o$ field, the resonance signals as observed in the rotating frame will be shifted in phase by the angle of rotation. In principle, rotation could be detected using only a single nuclear resonance in one cell by comparing its phase with that of a reference oscillator. However, the stability of the oscillator and the magnetic field required for making an inertial grade instrument would not be practical. In the MRG there are two kinds of nuclei in the same apparatus; both respond to the same magnetic field, and both contain the same rotation information. By comparing the relative phases of the two signals the angle of rotation can be obtained without independent knowledge

of the magnetic field. The value of the $H_o$ magnetic field can change without affecting the output of the gyro.

In order to facilitate the phase comparison, a second spin generator is constructed to be identical to the first but with its magnetic field $H'_o$ in the direction opposite to that of the first. In Figure 1, the second spin generator is behind the unopened access port. The light beams for the second spin generator are derived from the same lamps as the first through the use of polarizing beam splitters. The beam splitter in the pump beam can be seen in the cutout section. Magnetic shielding surrounds each of the two spin generators to provide isolation between them. The magnetic shielding also maintains the direction of the sensitive axis relative to the mounting reference surface of the instrument.

The phase comparison scheme by which the rotation angle is extracted is shown in Figure 2. The signals at the two frequencies from each spin generator are separated by means of filters and applied to phase measuring circuits. The outputs from the two phase measuring circuits are added to produce an error signal for controlling one of the magnetic fields and subtracted to provide the gyro output. With this scheme the difference of the outputs from the two phase detectors is exactly four times the angle of rotation of the gyro. The scale factor for the MRG is thus a simple whole number. It is not a function of the coil area or of any other physical characteristic of the instrumentation.

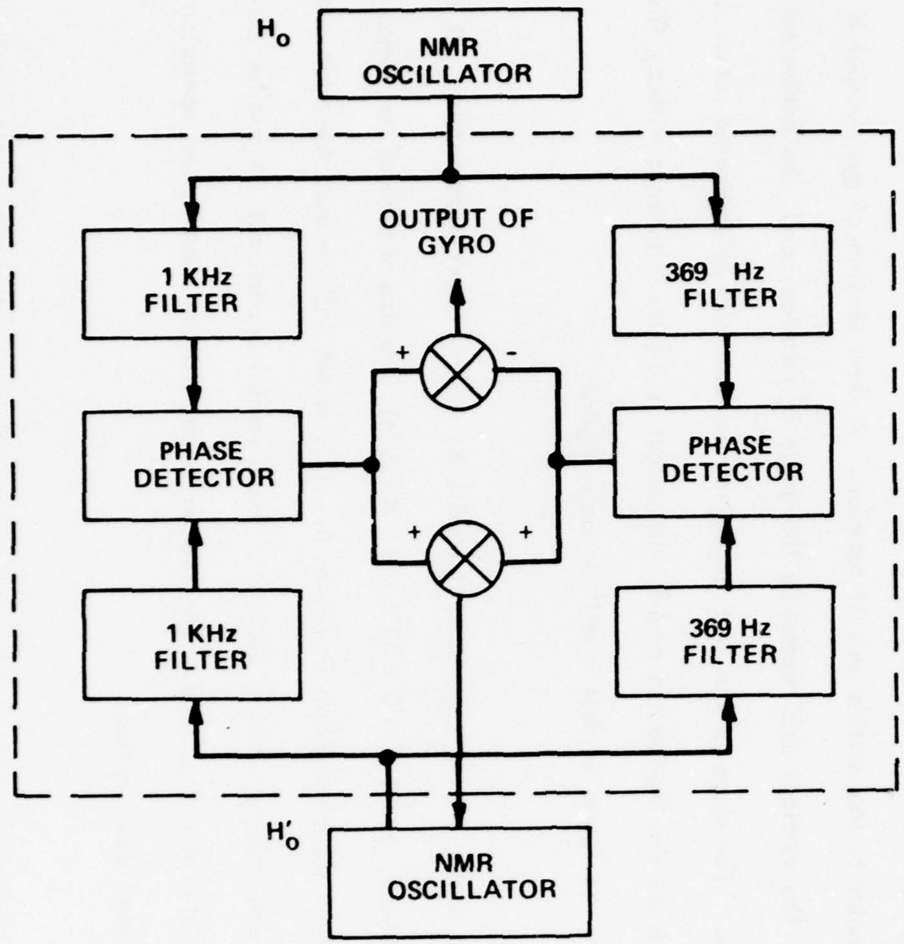


FIGURE 2 PHASE COMPARISON SCHEME USED IN THE EXPERIMENTAL MODEL

### 3. Description of MRG Models

Several models of the MRG have been designed and operated. Currently a breadboard model is being used as a test bed for demonstration and evaluation of experimental techniques and for investigating sources of rate bias in the gyro. A photo of the breadboard model is shown in Figure 3. A series of test runs were made with the breadboard model oriented with the input axis perpendicular to the earth's axis of rotation. A short section of gyro output is shown in Figure 4. The vertical axis represents the angle of rotation, and the horizontal axis represents time. The slope of the line thus gives the rate bias or indicated rate. In the instrumentation for the breadboard model, the output is digital with an auxilliary fine scale analog output. In future models it will be only digital.

Another model of the MRG, Experimental Model A, is now under construction. It is roughly triangular in shape, about 20 x 3 x 20 cm (8 x 3 x 8 in). The size of some of the components can be seen from the photograph in Figure 5. This model will be used for additional studies in measuring performance under a variety of experimental conditions. A smaller Experimental Model B is in the planning stage. The smaller model will be used in test operation of an advanced strapped down system.

In all these models as well as in the model shown in Figure 1 mercury cells of the same size, about 1cm in diameter are being or will be used. Magnetic resonance signals have been obtained with cells as small as 2mm in diameter. With further development the performance of smaller cells could be brought up to that of the 1cm cell. As a result, the size of the gyro could be further reduced beyond that shown in Figure 1.

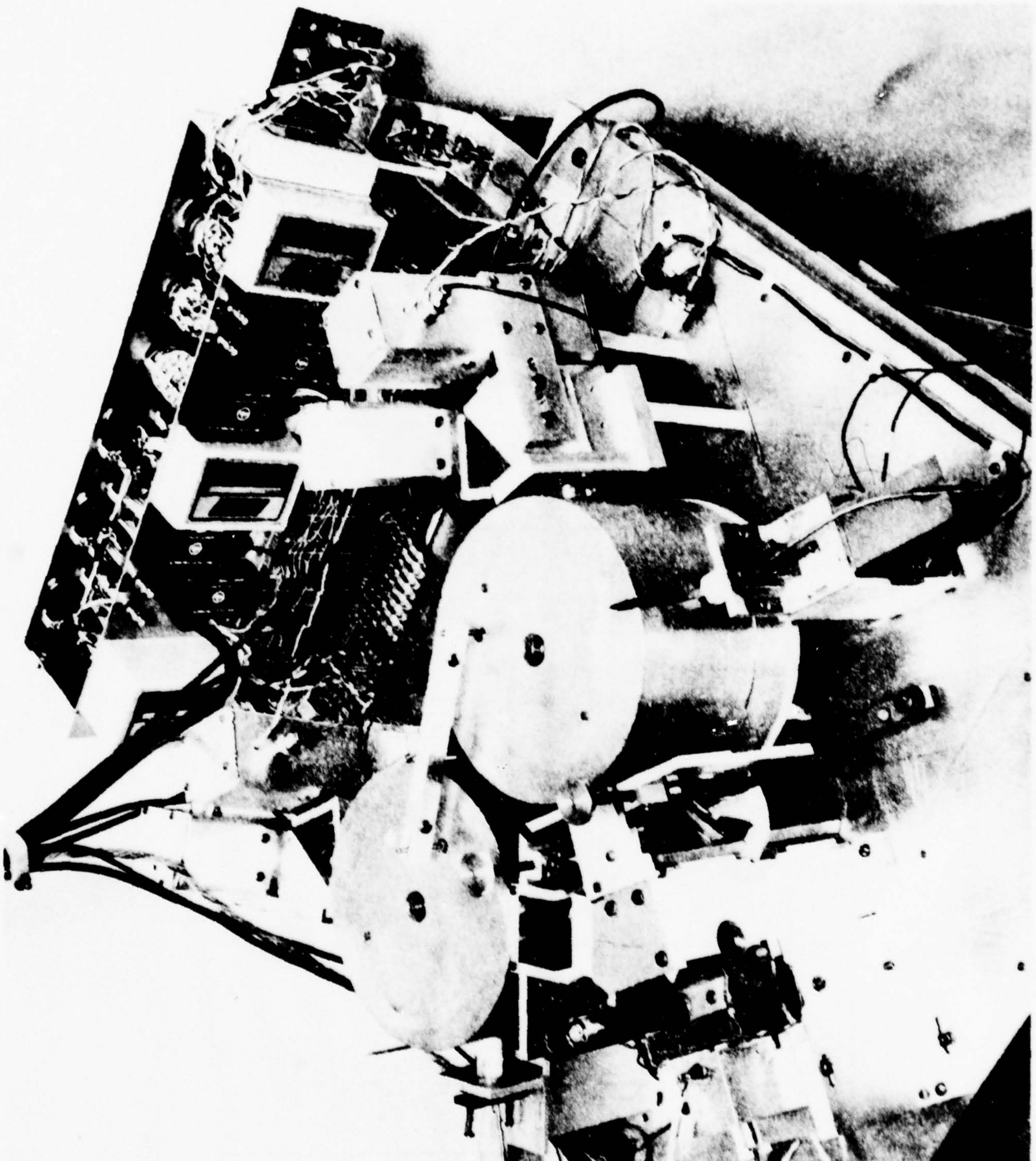

FIGURE 3 MRG

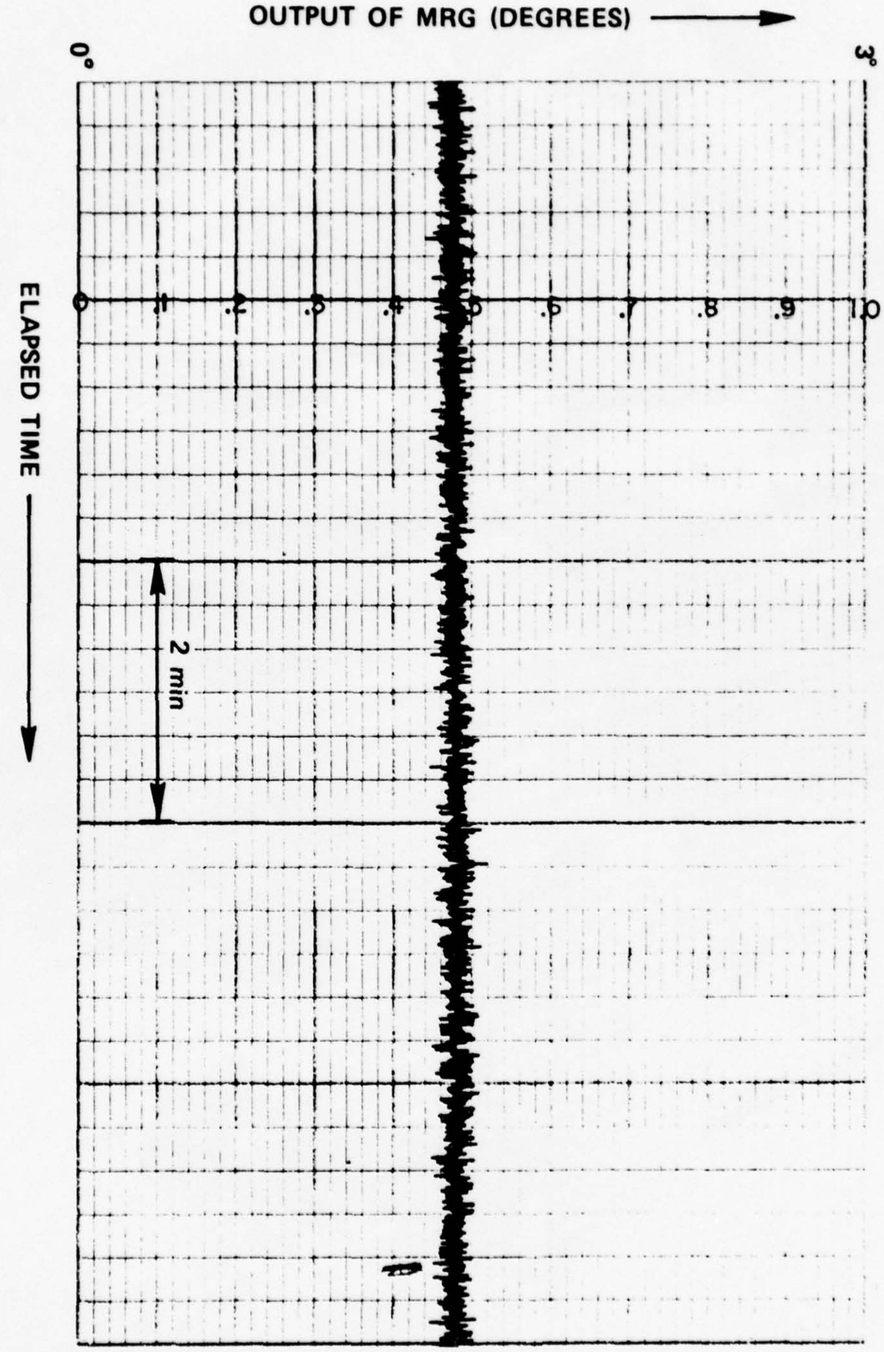


FIGURE 4. OUTPUT OF BREADBOARD MODEL OF MRG

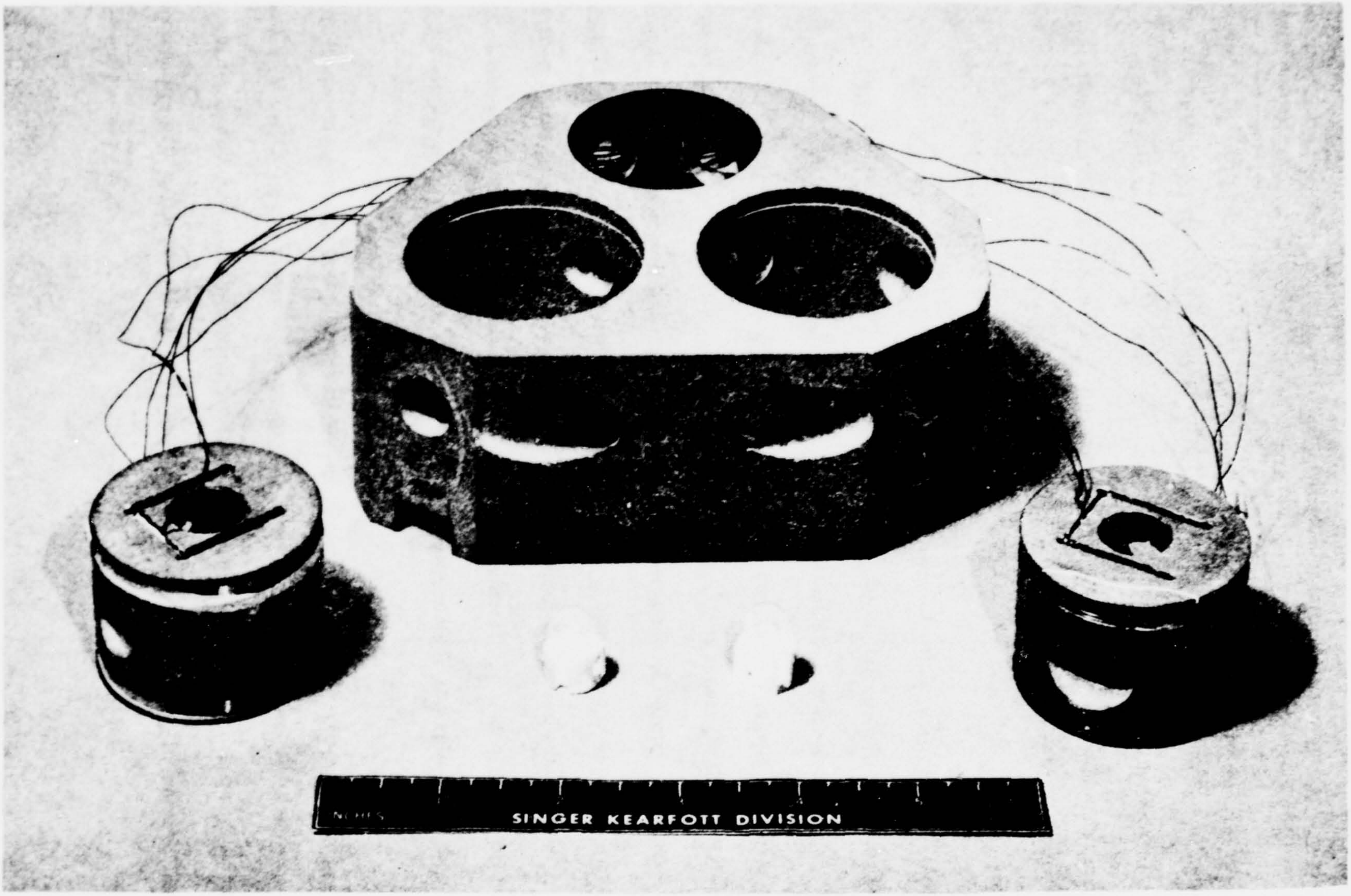


FIGURE 5 MRG EXPERIMENTAL MODEL COMPONENTS

4. Gyro Performance

The fundamental limit to the performance of the MRG is determined by the signal-to-noise ratios with which the resonances are detected and by the relaxation times of the mercury magnetic resonances. A theory of the effect of these parameters on gyro output has been developed and successfully verified with the breadboard model.[1]

The theory predicts a time-dependent and a time-independent error. The time-dependent contribution appears as a random wander in the gyro angle output. It is due to the accumulated noise-induced phase perturbations of each of the oscillator signals. If the signal-to-noise ratios (SNR) and relaxation times are assumed the same for all four signals, the error in angle after an hour can be summarized for combinations of signal-to-noise ratio and relaxation time as shown in Figure 6. Performance of 1, .1, and $.01^\circ/\sqrt{h}$ is shown by the diagonal lines for the parameters SNR and relaxation times. A combination of 80dB-Hz and 20 sec relaxation time or equivalent is required for $0.01^\circ/\sqrt{h}$ performance, a number associated with one nautical mile per hour (1 NMH) strapped down systems. The time-independent part is just the error introduced by the noise in making individual phase determinations. This error decreases as the observation time increases.

An additional limit to gyro performance is the rate bias stability. This is determined by the stability of those parameters that influence the frequency stability of the spin generators. Such parameters are phase shifts in the oscillators, shifts in resonance frequency due to the pump

1. I.A. Greenwood and J.H. Simpson, "Fundamental Noise Limitations in Magnetic Resonance Gyroscopes," Proceedings of the IEEE 1977 National Aerospace and Electronics 77CH1203-9 NAECON, p.1246.

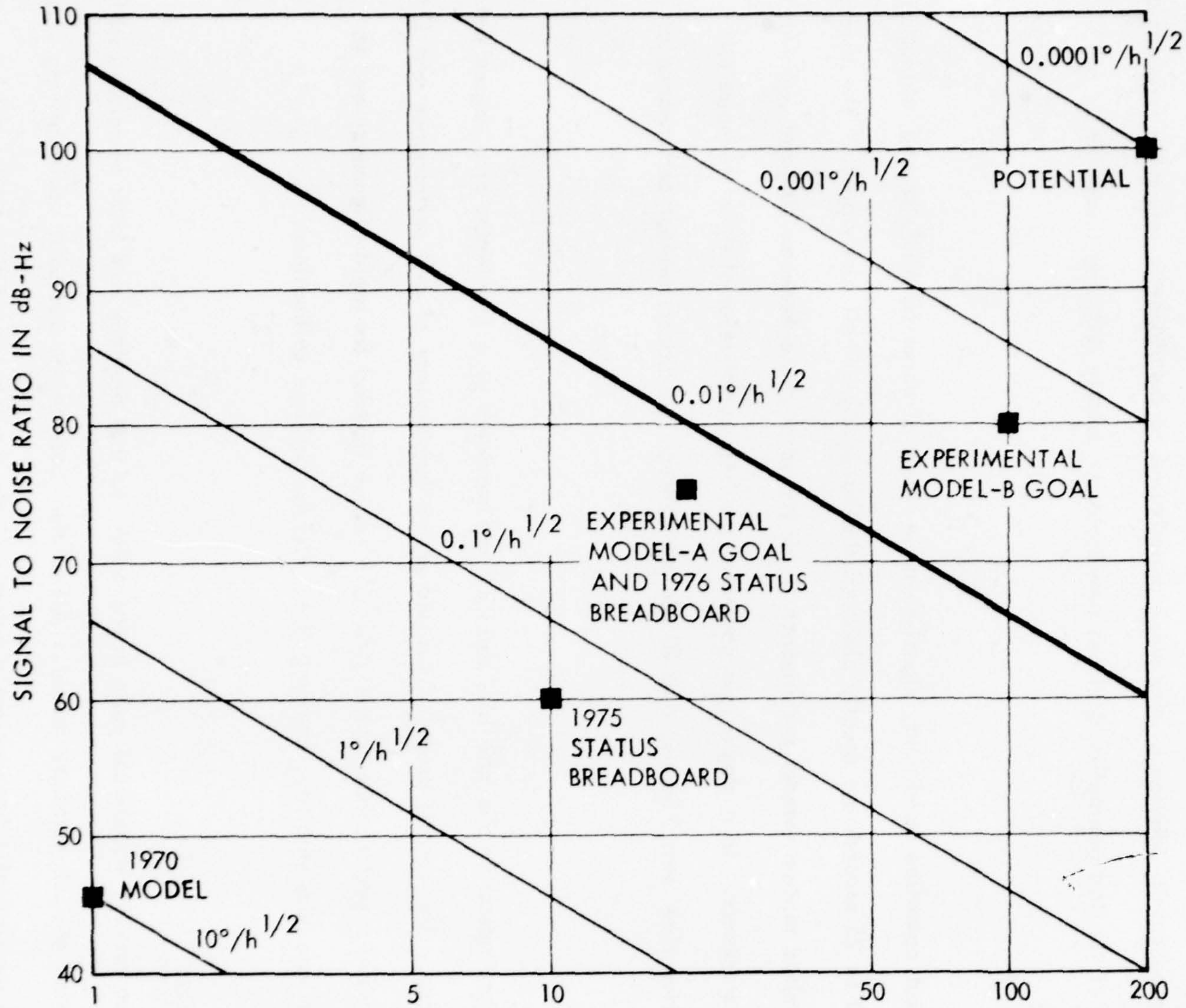


FIGURE 6 RANDOM WANDER AS A FUNCTION OF SNR AND RELAXATION TIME

beam and readout beam, and wall interactions. The primary function of the light beams are orientation of the nuclei and monitoring this precessional motion. The light interacting with the atoms produces in addition a very weak perturbation of the magnetic resonance frequencies. The design of the instrumentation includes provisions for greatly reducing these effects on gyro output.

Under typical operation conditions, signal-to-noise ratios of about 60-65dB-Hz and relaxation times of 20 to 25 seconds are usually observed simultaneously for all four signals. The theory of noise-limited random wander performance shows the error to be between .03 and $.04^{\circ}/\sqrt{h}$ for these parameters. In a single spin generator the best combination of signal-to-noise ratio and relaxation time was 75dB-Hz and 20 sec for a predicted random wander performance of about $.018^{\circ}/\sqrt{h}$.

In recent gyro operation the rate bias stability was measured at a few tenths of a degree per hour per hour. The current program is aimed at the improvement of cell performance and SNR to ultimately yield a performance in the $.002^{\circ}/\sqrt{h}$ region (needed for rapid alignment) and to improve the rate bias stability, bringing it to $.01^{\circ}$/hr between calibrations.

## 5. Discussion

There are no moving mechanical parts in the MRG, so that problems and costs associated with the fabrication of such parts are absent. All of the components and parts are relatively simple. No unusual mechanical tolerances are required. Only the interiors of the cells and lamps

require ultra-clean surfaces and these are built and sealed in as part of the fabrication of these components. Ultra-clean facilities need not be employed in assembling or servicing the MRG.

Those items requiring scheduled or unscheduled maintenance are low cost. For example, the cells and lamps are themselves not expensive and could be coded as throw away items. All other sub-assemblies could be serviced at an intermediate level of repair. Construction of current models is in terms of separate functional modules. Carrying this design philosophy through to the future model will simplify identification and correction of problem areas and simplify the supply support of consumable parts. In general, servicing should not require a high level of training or skill.

The predicted lifetime of the MRG is encouraging. A goal of 50,000 hours is realistic and should be met. Factors contributing to the long lifetime include the fact there are no moving parts, no thermionic emitters, no electrodes involving glass to metal seals, and no high voltages. All circuitry uses standard solid state devices most of which are adaptable to LSI and hybrid techniques. The mercury lamps are electrodeless and are excited by rf.

The main failure mode should be long term, very gradual degradation of the parameters signal-to-noise ratio and relaxation time. Such gradual degradation will result in a gradual loss of accuracy rather than sudden catastrophic failure. Simple monitoring of parameters will provide criteria for scheduled maintenance to preclude functional failures.

With low acquisition cost, high MTBF, long life, and easy forward level servicing, cost of ownership will be relatively attractive.

The present program consists of work to improve rate bias stability and noise-limited performance. These findings will be used in the program of model design and test now in progress. The goal of this work is the design of a group of gyros for use in a 1 NMH strapped down navigator that fits the format of a standard 3/4 ATR box. Other versions, some of smaller size are possible for different applications.

## 6. Acknowledgements

The authors thank J.P. Callahan of Singer-Kearfott Division for his careful review of this paper and for his helpful comments.

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BRIEFING TITLE

MULTI-FUNCTION INERTIAL REFERENCE ASSEMBLY (MIRA)

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PRELIMINARY FEASIBILITY ASSESSMENT OF MULTI-FUNCTION

INERTIAL REFERENCE ASSEMBLY (MIRA)

BY

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John M. Perdzock, Air Force Flight Dynamics Laboratory, WPAFB, Ohio

Robert C. Burns, McDonnell Douglas Corporation, St. Louis, MO

PRESENTED TO: 11th JOINT SERVICES DATA EXCHANGE FOR INERTIAL SYSTEMS, 26-28 OCTOBER 1977, NEWARK AIR FORCE STATION, OHIO

....This paper is UNCLASSIFIED

# PRELIMINARY FEASIBILITY ASSESSMENT OF MULTI-FUNCTION INERTIAL REFERENCE ASSEMBLY (MIRA)

by

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## ABSTRACT

The multiplicity of inertial and air data sensors on advanced Air Force fighters and transport aircraft is contributing significantly to sharply increasing avionic costs. A potential solution is the development of a Multi-function Inertial Reference Assembly (MIRA) subsystem which satisfies all on-board inertial and air data reference data requirements for flight control, navigation and weapon delivery. As a first step in assessing the feasibility of the MIRA concept the Air Force awarded a two year duration study contract to McDonnell Douglas Corporation in June 1976.

This paper discusses mission and performance goals established for MIRA feasibility studies covering flight control, navigation and weapon/cargo delivery as applied to the fighter aircraft (F-15) and a transport aircraft. The relationship between the key technical issues of concern and the feasibility criteria and the methodology to perform the trade-offs which impact life cycle costs are described. Functional performance and reliability requirements are shown. Computational requirements for a representative MIRA system is summarized. Computer programs were used to evaluate time histories of sensor and system error propagation and to assess the impact on flight control system control laws as MIRA sensors are installed at various aircraft installation locations. The criteria defined to perform the preliminary feasibility assessment is discussed. Comparative studies of life cycle costs show a saving estimate in excess of 69 million dollars for MIRA application to a quantity of 144 fighters over a 15 year operational life. Cost savings for transport applications are qualitatively significant, particularly for the operations and support cost element. The results of ring laser gyro (RLG) and tuned rotor gyro (TRG) studies of performance and reliability improvements required are summarized. The laboratory demonstrations performed by three subcontractors with operating redundant equipment, which shows software capability to provide fault coverage, is discussed.

Technology projections indicate that by 1980 performance and producibility will be nearing maturity for sensors and microprocessors and that software techniques will be developed which provide adquate fault coverage and redundancy management for both skewed and multi-unit sensor, LRU and system architecture.

The results to date have shown that questions relating to key issues have been satisfactorily answered with the conclusion that the MIRA program should proceed into further detailed system configuration studies, which specifically address commonality, test and maintenance standardization trade offs, and the preparation of a specification for a selected best MIRA candidate configuration which in turn can be used in procurement of equipment for flight test verification of MIRA concepts in the MIRA advanced development program.

## I. INTRODUCTION

Current military fighter and transport aircraft use avionic equipment which generally follows a federated or a consolidated system architecture. This has resulted in various inertial and air data functions being replicated in sensors being tailored and dedicated to specific subsystem tasks, for example, navigation: Inertial Navigation System (INS), Attitude and Heading Reference Systems (AHRS) and Air Data Computer; flight control: rate gyros, accelerometers and dynamic pressure sensors; weapon delivery: lead computing gyros and accelerometers.

With the progress being made with inertial sensors, such as strapped down tuned rotor gyros and ring laser gyros, and large scale integrated circuit microprocessors, the question has been posed which asks "Is it possible to configure a multi-function inertial reference assembly subsystem which (a) provides functional outputs adequate for navigation, flight control and weapon delivery, (b) achieves the required mission and safety-of-flight reliability, and (c) results in significant life cycle cost savings when compared with current approaches?".

In response to this question, the Air Force, under joint sponsorship of Flight Dynamics Lab, Avionics Lab, and Aeronautical Systems Division, created the MIRA program to determine the eventual payoff when MIRA is applied to advanced Air Force fighters, transports and RPVs of the 1980-1990 time period (Figure 1).

The specific objective and approach is shown in Figure 2. In order to implement the program the Air Force partitioned the MIRA program into two phases: Phase 1, Feasibility, which was awarded to McDonnell Douglas Co. (MDC), St. Louis, Missouri in June 1976 and will end in July 1978, (Ref. 1), and Phase 2, Verification, which is currently scheduled to be started in Air Force fiscal year 1979 as shown in Figure 3. MIRA application would take place starting in the early 1980s. MDC has put together a MIRA team being led by McDonnell Aircraft (MCAIR) in St. Louis where fighter studies are also being concentrated, together with Douglas Aircraft (DAC) for transport studies and subcontractors Honeywell, Minneapolis, Minn., Singer-Kearfott, Little Falls, N.J., and Litton, Woodland Hills, CA., for support studies. Subcontractor studies emphasized strapped down system, ring laser gyro (RLG) and tuned rotor gyro (TRG) implementation technology, analytical trade-off studies and hardware demonstrations. The activities and studies described in the following sections of this paper were performed as part of Task 1, Phase 1. Task 1 is aimed at making a preliminary assessment of feasibility of the MIRA concept for both fighter and transport aircraft through analytical studies performing comparative analyses, and laboratory demonstrations with available hardware.

Detailed system configuration studies and the selection of a recommended MIRA system is presently in work under Task 2. During Task 3 the development specification will be written for use in procurement of equipment for Phase II.

Figure 4 illustrates conceptually how the MIRA is envisioned to functionally replace the inertial and air data references on current aircraft. MIRA, as a subsystem which has adequate performance and reliability (including redundancy), feeds the using subsystems through the data bus network, MIL-STD-1553A.

Key issues to be resolved in determining the feasibility of the MIRA concept to effect cost savings are shown in Figure 5. Multi-function requirements need definition, such as sensor accuracy required for long duration flights and the wide dynamic range for fighter application; sensor location effects, which include the vibration effects on redundant and/or separate sensors when operated in a flexible airframe; failure detection and isolation which places demands on microprocessors to perform within real time in order to keep the fault detection and isolation at high confidence levels, the nuisance alarms at low levels, and to accomplish the necessary redundancy management for system reconfiguration. Adequate reliability must be achievable in a practical sense and modularity, which will permit flexibility of application is essential.

The MIRA road map of activity is shown in Figure 6. This paper will cover the sign posts leading up to crossing over the bridge. Because it is believed that the fighter aircraft application will impose the more demanding requirements of the MIRA, most of the ensuing discussion is addressed to fighter analysis. A MIRA that is feasible for the fighter should be capable of adaptation to meet the normal and unique performance requirements of a transport aircraft.

## II. SYSTEM REQUIREMENTS

The latest Air Force operational fighter, F 15A, was selected as the principal data base source for comparative fighter studies, supplemented with F-4 and F-18 data (Figures 7 and 8). A representative aircraft was selected for comparative transport studies. Each aircraft has a high authority fail-safe control augmentation (CAS) flight control system. Inertial navigation is required on each aircraft. The F-15 specializes in air superiority weapon delivery and has excellent air-to-ground capability. The transport performs cargo and troop drop missions.

Missions were defined for fighters and transports which were representative of combat conditions. The fighter mission lasting about 2 hours involving high dynamics, and the transport mission being approximately 30 hours, involves numerous mission segments where landings are made and drops occur. Mission performance goals were defined to be 1 NM/hr for inertial navigation, 8 milliradian for air-to-surface weapon delivery, and Level 1, MIL-F-8785 flying qualities. Air-to-air weapon delivery performance is classified and for the purposes of this paper has not been included.

Output signal requirements were determined based upon allocations to functions for various current avionic equipments. Figure 9 lists some of the key parameters which were taken from a detailed list which showed a total of 117 outputs.

## III. ANALYSIS

Analysis of computational requirements are summarized in Figure 10. A preliminary analysis of function commonality showed that F-15 air inlet controller requirements were so aircraft/engine oriented that the air inlet requirements should be removed from the main modules. It should be noted that the processing speed (Kops) and refresh rate would be decreased (approximately a factor of four) for the transport, but that memory word storage requirements would stay about the same.

Flight control key issues, structural modes frequency and amplitude, gain and phase margins, fuselage stations for MIRA installation and lever arm effects, were analyzed. Results, illustrated in Figure 11, showed that when sensors are combined the best location for flight control is in a zone around fuselage station (F.S.) 425 but that the sensor LRU could be located as far forward as F.S. 225 before CAS would go unstable without change in control laws. The analysis also showed the methodology of how control laws changes could be made to permit LRU location to be moved up to the most available forward location (just aft of the radar) and still provide Level 1 handling qualities.

Figure 12 reports the analysis results for the fighter hardware MTBF reliability apportionment. The MTBF is based upon parts count. For comparative purposes, the safety-of-flight reliability is taken care of by having mechanical back-up for flight control. Figure 13 shows transport reliability results. The 150 hour MTBF is a minimum requirement and should not be interpreted as being the actual MTBF. In reality the actual MTBF should be significantly higher. The transport mission reliability of 0.99929 is required for each of three different types of missions (training, deployment augmentation, intratheater support) defined for reliability purposes.

## IV. FEASIBILITY CRITERIA

All of the previous discussion has been oriented to establishing the MIRA requirements and performing associated analysis in preparation for being able to respond to the preliminary feasibility assessment criteria which consists of the six categories, all interrelated, shown in Figure 14.

Producibility data on RLG and TRG sensors, which covered fabrication, assembly and test, and the methodology associated with each sensor type, was supplied by each equipment subcontractor. Because producibility is related so closely with proprietary data the review of the data was done at each subcontractor facility with only MDC and government personnel in attendance. The conclusion being that TRG technology is very much like the present gimballed TRG technology and therefore, represents minimum risk. However, more experience is required with the RLG technology, because there are still size and performance developments in work. Within 1 to 3 years the RLGs should have proven producibility based upon current development trends.

The cost savings potential was handled on a total life cycle cost (LCC) basis (Figure 15). MCAIR, DAC and each subcontractor postulated a system and a proposed mechanization based upon the MIRA performance goals and outputs defined by MDC documents. Equipment costs were supplied to MDC which, in turn, were input into a LCC model at MDC. The MDC LCC model was a combination of the RCA PRICE model and a previously used MCAIR advanced concepts cost model (ACCM). LCC were broken into 3 functional elements: (1), RDT&E, (2), Investment, and (3), O&S (Operations and Support). For comparative studies the Figure 16 shows the F-15A avionics impacted by MIRA which would be replaced entirely or partially. The uninstalled weight of this equipment is approximately 187 pounds. The 187 pounds includes 28 pounds of equipment which would not be replaced by MIRA, e.g., the SDRS tape recorder, the AIC valve drive circuitry and the NCI. Therefore, only 159 pounds of F-15 avionics would be in actuality replaced by MIRA. A MIRA configuration which functionally replaces the 159 pounds of F-15 equipment is shown in Figure 17. (Figure 17 is used for cost comparative purposes only, i.e., its performance is equivalent as much as possible to the performance of the equipment replaced.). The equipment weight estimates f Figure 17 is projected to range from 50 to 60 pounds. It should be noted that survivability requirements imposed by MIRA requires separate LRUs. Each MRU is capable of autonomous functional operation.

Fighter cost savings, Figure 18, are shown to range from 69M to 80M dollars. This range of min to max is based upon (a) subcontractor data, (b) is dependent of sensor mechanization, and (c) includes the impact of technology improvements projected to take place by 1980 with sensors and LSI microprocessors.

In performing the cost comparison for transports the situation is slightly different from the fighter since there is no weapon delivery/lead computing gyro requirements. The transport currently has a dual inertial sensor system (ISS) and a dual air data system (Figure 19). By integrating LRUs for the MIRA configuration, improved mission reliability results due to dual processing capability, slightly improved production costs results (Figure 20), and due to commonality and standardization of LRUs, qualitative significant savings are expected in O and S cost element.

Assessment of functional requirements satisfied and identification of performance improvements required were made with the use of subcontractor data and MCAIR math modelling studies using a computer program called SIMSIN, which can evaluate sensor and system performance over arbitary flight profiles and provides time history of error propagation. The results showed that transport functional position and velocity requirements can be met with current TRG and RLG systems but that product enhancement improvements for production are needed for fighters due to the high dynamic environment (Figure 21). Each MIRA subcontractor is at a different level in verifying his equipment capability, which is proprietary, and therefore the "present capability", Figure 21, is not meant to be used to single out a particular subcontractor, but rather is to be considered as an industry-wide combined average. By the end of 1980 it is expected that the improved performance for fighters application will be demonstrated, by several equipment suppliers, to at least brassboard level.

The impact of reliability on life cycle costs is significant. Studies showed that MIRA needs an improvement goal of 11.3 over current operational experience (Figure 22). To achieve this goal, an approach to reliability improvement in both design and management, is believed achievable for MIRA (Figure 23). This type of methodology is currently being used on the F-18 and should start showing payoff benefits within the next two years.

## V. LABORATORY DEMONSTRATIONS

In addition to analytical studies, hardware laboratory demonstrations were performed by each MIRA subcontractor.

The hardware demonstrations were aimed at demonstrating key technical issues such as software redundancy management, fault detection and isolation, sensor skewing, cluster skewing, cluster separation, frequency response, resolution, noise content, quantization, failure mode effects, and open and closed loop operation.

During each hardware demonstration the operation was first demonstrated in a full-up configuration. Simulated failures (hard over, slow over, null) were entered into the system by the operator and the signal outputs recorded and compared with the full-up performance. The impact upon flight control, navigation and weapon delivery outputs were each assessed with appropriate criteria for fault coverage. Honeywell's RLG demonstration set-up is shown in Figure 24; Singer-Kearfott TRG set-up is shown in Figure 25; Litton TRG set-up is shown in Figure 26. It should be noted that demonstration equipments were made available at no cost to MDC or the Air Force.

Each subcontractor's demonstration plan, procedure and criteria was tailored to be supplemental to the analytical tasks performed and was based upon available equipment.

Therefore, it was not required that the equipment demonstrated be configured as a MIRA system, partitioned as a MIRA system, or even of flight worthy construction, even though some of it was.

## VI. RESULTS, CONCLUSIONS AND RECOMMENDATIONS

The results and conclusions of key issues discussed in Figure 5 are shown in Figure 27. Overall conclusions for Task 1, shown in Figure 28, range from MIRA feasibility established to the need for a supplemental effort to take the hardware demonstrated in the laboratory and evaluate the software redundancy management and/or fault detection and isolation capability under dynamic moving vehicle conditions. Thus providing added feasibility in a environment which provides translation inputs to the system.

Recommendations coming out of Task 1 studies are shown in Figure 29. As a follow-up to the second recommendation, the Litton system was tested (Sept. 77) in the AFAL mobile evaluation laboratory. Honeywell and Singer-Kearfott systems are scheduled for testing in the first half of calendar year 1978.

The Task 1 studies, analysis, results, conclusions and recommendations were formulated in a milestone technical report and approved by the Air Force in August 1977 (Reference 2). The MIRA activities are currently concentrated on refining the configuration candidate studies in preparation for selecting a final configuration. More detailed analysis will be made of the selected configuration. The final report will include the preliminary MIRA specification, the life cycle cost criteria, application to advanced aircraft and the supporting rationale.

## VII. ACKNOWLEDGEMENTS

A key factor in the success of the program has been due to the establishing of feasibility criteria early, identifying key technical issues, keeping the program objectives constantly in front and having a very closely knit and working MIRA team. The a thors would like to acknowledge the contribution of each member of the MIRA team: the Air Force Flight Dynamics Lab, Air Force Avionics Lab, and Air Force Aeronautical Systems Division, and from each industry member, represented by Mr. G. C. Jackson, McDonnell Aircraft Co., Mr. E. Rodriguez, Douglas Aircraft Co., Mr. C. Senechal, Honeywell, Mr. M. Goldstein, Singer-Kearfott, and Mr. H. Daubert, Litton.

## REFERENCES

1. Air Force Contract No. F33615-76-C-3132, Multi-Function Inertial Reference Assembly

2. Report MDC A4780, dated 12 Sept 1977, Multi-Function Inertial Reference Assembly (MIRA), Interim Report No. 2, Task 1 - Define Functional and Performance Requirements for MIRA and Assess Feasibility

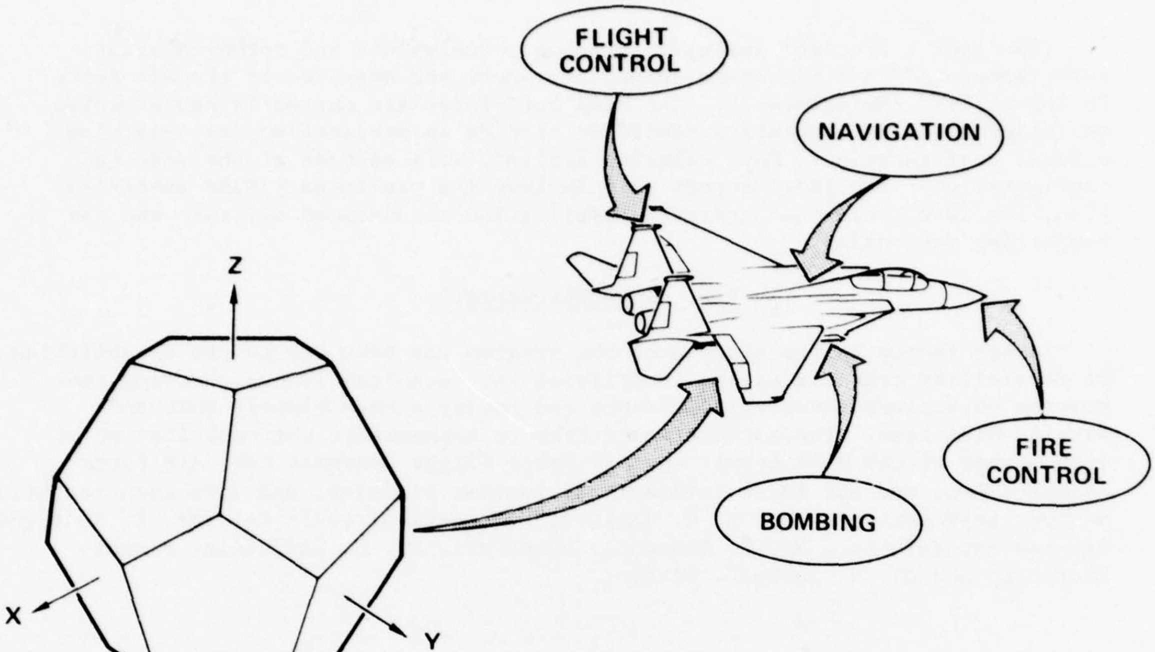


**FIGURE 1**
**MULTI-FUNCTION INERTIAL REFERENCE ASSEMBLY (MIRA)**
(An Avionics Subsystem Concept for Application to Advanced Air Force Aircraft of the 1980-1990s)

- REDUCE LIFE CYCLE COST OF INERTIAL EQUIPMENT
- SYSTEMS ANALYSIS TO DETERMINE BEST CONFIGURATION OF INERTIAL/AIR DATA SENSORS FOR THE FUNCTIONS OF:
  - FLIGHT CONTROL
  - WEAPON DELIVERY
  - NAVIGATION

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**FIGURE 2**
**OBJECTIVE AND APPROACH**

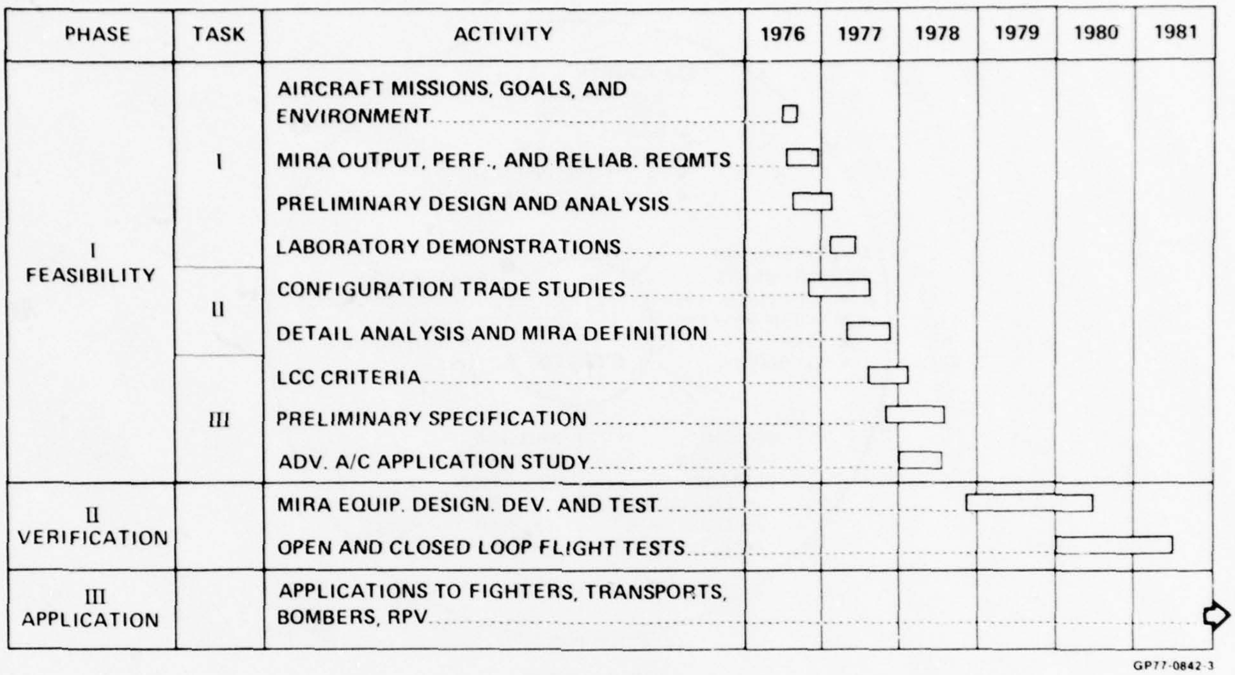


**FIGURE 3**
***MIRA PROGRAM SCHEDULE OVERVIEW***

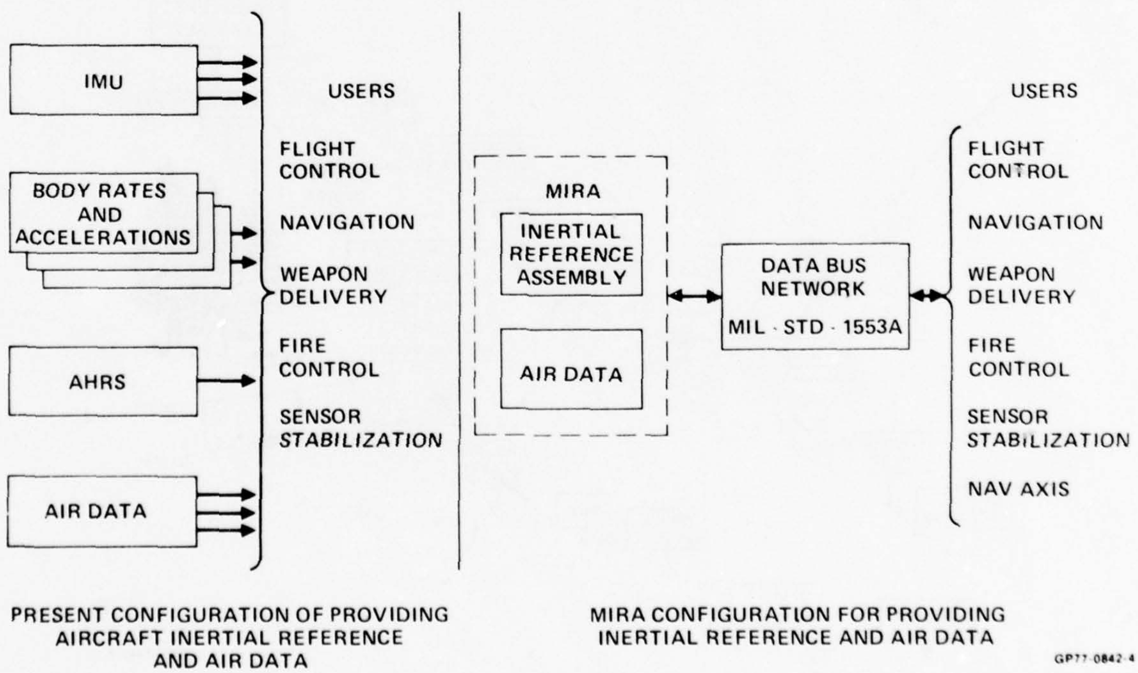


**FIGURE 4**
**MIRA INTERFACE CONCEPT COMPARISON**

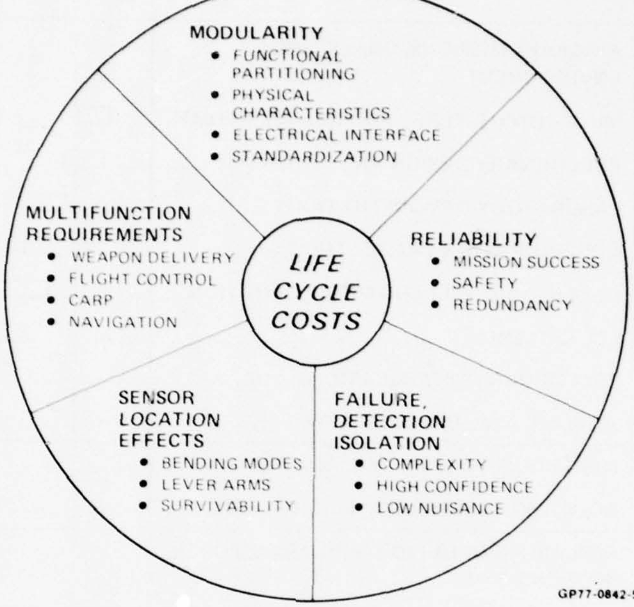


**FIGURE 5**
**MIRA KEY ISSUES**

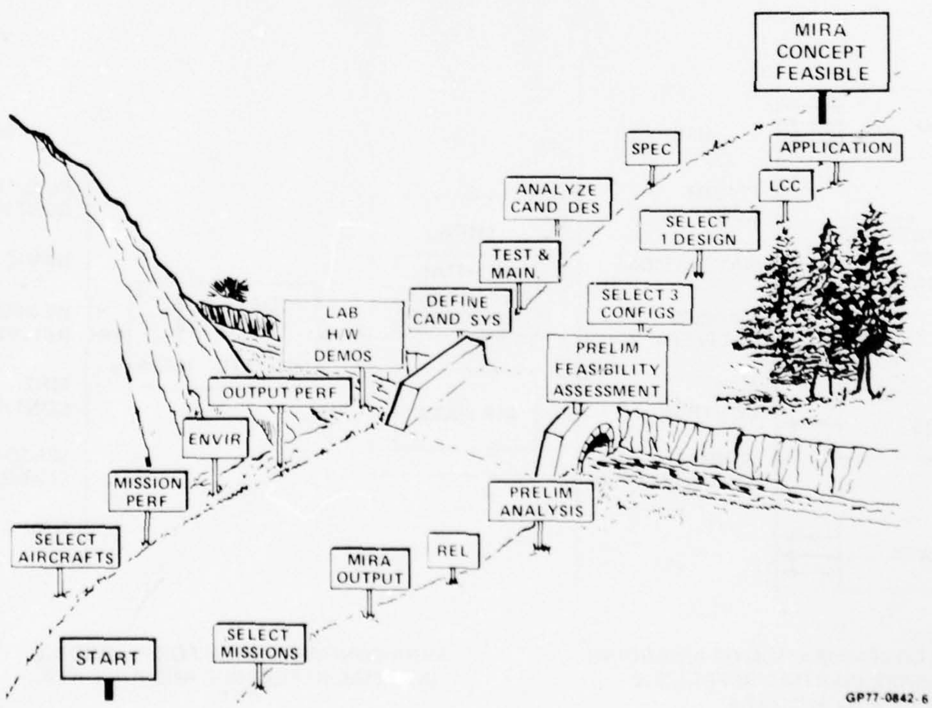


**FIGURE 6**
**PHASE I ACTIVITY - ROAD MAP**


**FIGURE 7**
**F-15A AIRCRAFT**

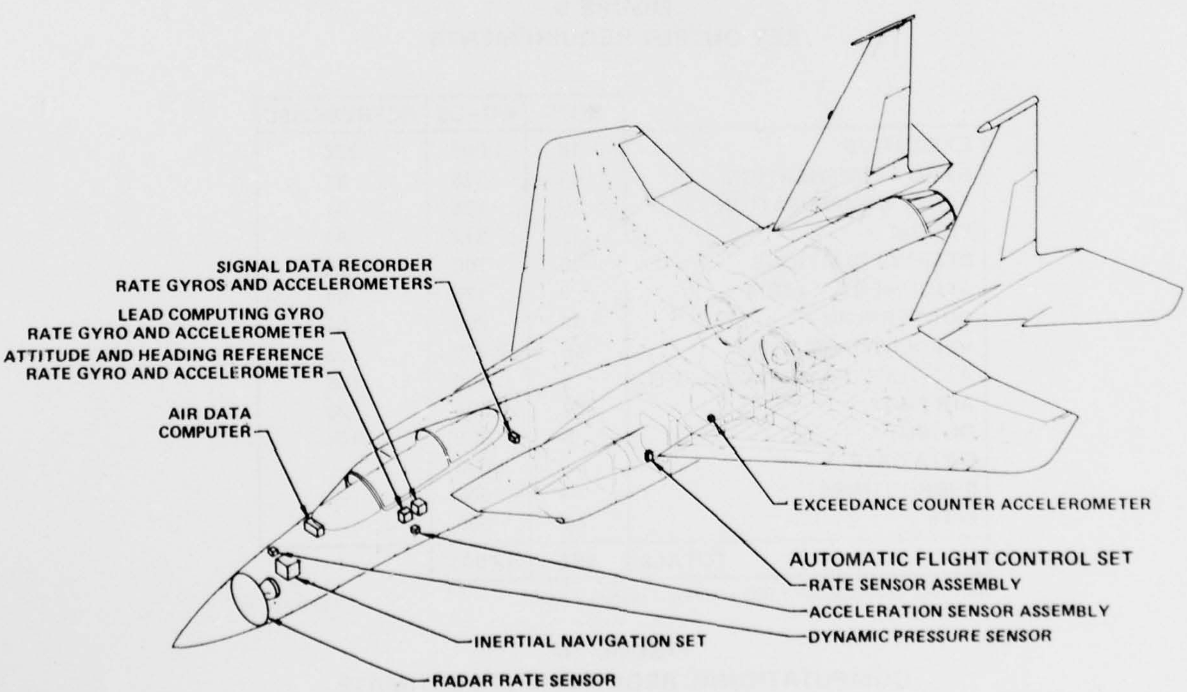


**FIGURE 8**
**F-15 INERTIAL/AIR DATA SENSORS**

| | OUTPUT PARAMETER | RANGE | ACCURACY STANDARD DEVIATION | FORM | ITERATIONS PER SECOND | MTBF |
|---|---|---|---|---|---|---|
| 1. | LATITUDE | ±90° | 1 NM/HR | 1553A MUX | 25 | 3,000 |
| 2. | LONGITUDE | ±180° | 1 NM/HR | | 25 | 3,000 |
| 3. | INERTIAL ALTITUDE | −1,000 TO 80,000 FT | 250 FT | | 25 | 3,000 |
| 4. | NORTH/EAST VELOCITY (2) | ±4,100 FPS | 2.5 FPS RMS | | 80 | 15,000 |
| 5. | VERTICAL VELOCITY | ±2,050 FPS | 2 FPS RMS | | 80 | 15,000 |
| 6. | TRUE HEADING | ±180° | 6 ARC MIN | | 80 | 7,500 |
| 7. | DRIFT ANGLE | ±35° | 0.1° TO 1° | | 25 | 9,000 |
| 8. | AZIMUTH ANGLE | ±180° | 6 ARC MIN | | 80 | $10^7$ |
| 9. | ELEVATION ANGLE | ±90° | 2 ARC MIN | | 80 | $10^7$ |
| 10. | ROLL ANGLE | ±180° | 2 ARC MIN | | 80 | $10^7$ |
| 11. | BODY LINEAR ACCELERATION (3) | ±390 FT/SEC$^2$ | 0.33 FT/SEC$^2$ | | 80 | $10^7$ |
| 12. | BODY YAW/PITCH RATE (2) | ±85°/SEC | 0.02°/SEC | | 80 | $10^7$ |
| 13. | BODY ROLL RATE | ±360°/SEC | 0.02°/SEC | | 80 | $10^7$ |
| 14. | BAROMETRIC ALTITUDE | −1,000 TO 80,000 FT | 2 FT OR 0.2% | | 25 | $10^7$ |
| 15. | TRUE ANGLE OF ATTACK $\alpha$ | −10° TO 35°F | $0.12 + 0.004\,\alpha + 10$ | | 25 | $10^7$ |
| 16. | INDICATED AIRSPEED $V_I$ | 14 TO 1,600 KTS | 4 KTS $V_I < 100$<br>2 KTS $V_I > 100$ | | 25 | $10^7$ |
| 17. | TRUE AIRSPEED | 60 TO 1,710 KTS | 5 KTS | | 25 | $10^7$ |
| 18. | MACH NUMBER | 0.09 TO 3 M | 0.005 TO 0.01 | | 25 | 7,500 |
| 19. | TOTAL TEMPERATURE | −62°F TO 233°F | 0.44° | | 25 | 9,000 |
| 20. | FIRST RAMP SERVO DRIVE | ±50 MA | INTO 100 Ω | LOAD | CONTINUOUS | $10^7$ |
| 21. | DIFFUSER RAMPS SERVO DRIVE | ±50 MA | INTO 100 Ω | LOAD | | $10^7$ |
| 22. | BYPASS SERVO DRIVE | ±50 MA | INTO 100 Ω | LOAD | | $10^7$ |
| 23. | NON MUX BUS DISCRETES (10) | ON-OFF | N/A | WIRES | RANDOM | 30,000 |
| 24. | MUX BUS DISCRETES (10) | ON-OFF | N/A | 1553A MUX | | 30,000 |
| 25. | REACTION TIME | 10 MINUTE (MAX) FOR GYRO COMPASS ALIGN: 3 MINUTE (MAX) FOR STORED HEADING ALIGN | | | | |

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**FIGURE 9**
**KEY OUTPUT REQUIREMENTS**

| | KOPS | WORDS | REFRESH/SEC |
|---|---|---|---|
| EXECUTIVE | 16 | 1,000 | 128 |
| GYRO COMPENSATION | 41 | 538 | 64 |
| ACCEL COMPENSATION | 10 | 126 | 64 |
| FDI/RM | 15 | 312 | 64 |
| DESIGN EQUATIONS | 10 | 700 | 64 |
| ALIGNMENT MATRIX | 8 | 175 | 64 |
| QUATERNION | 39 | 900 | 64 |
| VELOCITY/POSITION | 45 | 1,200 | 32 |
| ATTITUDE/RATES/ACCEL, ETC | 4 | 500 | 128 |
| AIR DATA | 364 | 3,500 | 20 |
| OUTPUT | 5 | 350 | A/R |
| DATA BASE | – | 1,500 | – |
| SUBROUTINES | – | 600 | – |
| BITE | 40 | 600 | – |
| TOTALS | 597 | 12,001 | |

Note: Air inlet requires 1,000 additional words, 7 KOPS

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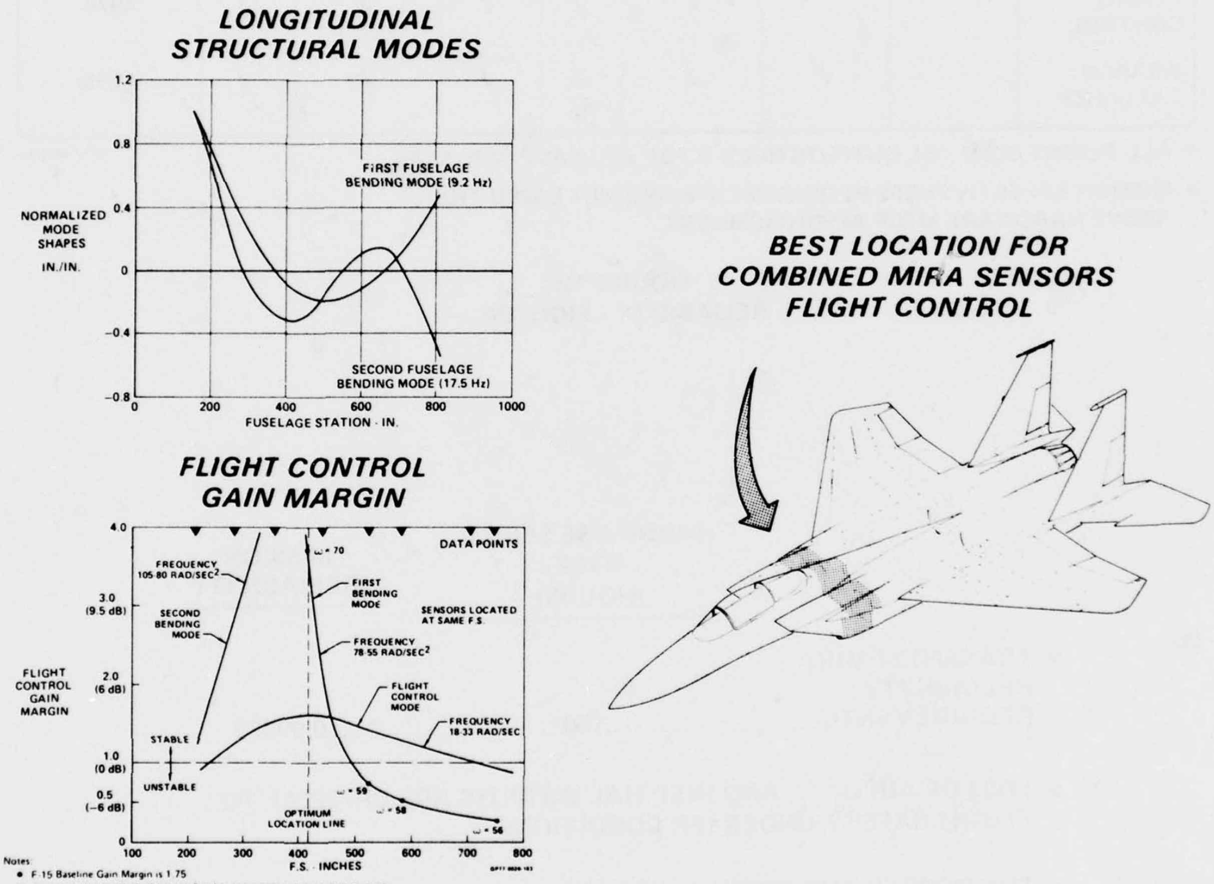
**FIGURE 10**
**COMPUTATIONAL REQUIREMENTS ESTIMATE**
(Representative MIRA System - Fighter)




Notes:
- F-15 Baseline Gain Margin is 1.75
- Analysis includes effect of 1st and 2nd fuselage mode and 1st stabilator mode
- No compensation added to improve stability

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**FIGURE 11**
**FIGHTER ENVIRONMENT**

| MIRA FUNCTION | POSITION | HEADING | ATTITUDE | ANLR BODY RATE | ACCEL | VELOCITY | AIR DATA | FIGHTER APPORTIONED HARDWARE SERIES MTBF (HR) |
|---|---|---|---|---|---|---|---|---|
| NAVIGATION | ✓ | ✓ | | | | ✓ | ✓ | 1071 |
| FLIGHT CONTROL | | | ✓ | ✓ | ✓ | ✓ | ✓ | 4970 |
| WEAPON DELIVERY | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 5596 |

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- ALL FLIGHT CONTROL OUTPUTS NEED TO BE AT LEAST FAIL-SAFE
- MISSION EFFECTIVENESS REQUIREMENTS ARE MET USING THE ABOVE HARDWARE MTBF APPORTIONMENT

FIGURE 12
RELIABILITY - FIGHTER

| | HARDWARE SERIES MTBF (HOURS) | MISSION RELIABILITY |
|---|---|---|
| • TRANSPORT MIRA RELIABILITY REQUIREMENTS | 150 | 0.99929 |

- LOSS OF AIR DATA AND INERTIAL OUTPUTS ARE CRITICAL TO FLIGHT SAFETY UNDER IFR CONDITIONS
- THE DEGREE AND CRITICALITY OF MIRA FAILURE WILL BE ESTABLISHED WHEN DETAILED SAFETY AND HAZARD ANALYSIS ARE PERFORMED IN TASK II

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FIGURE 13
RELIABILITY - TRANSPORT

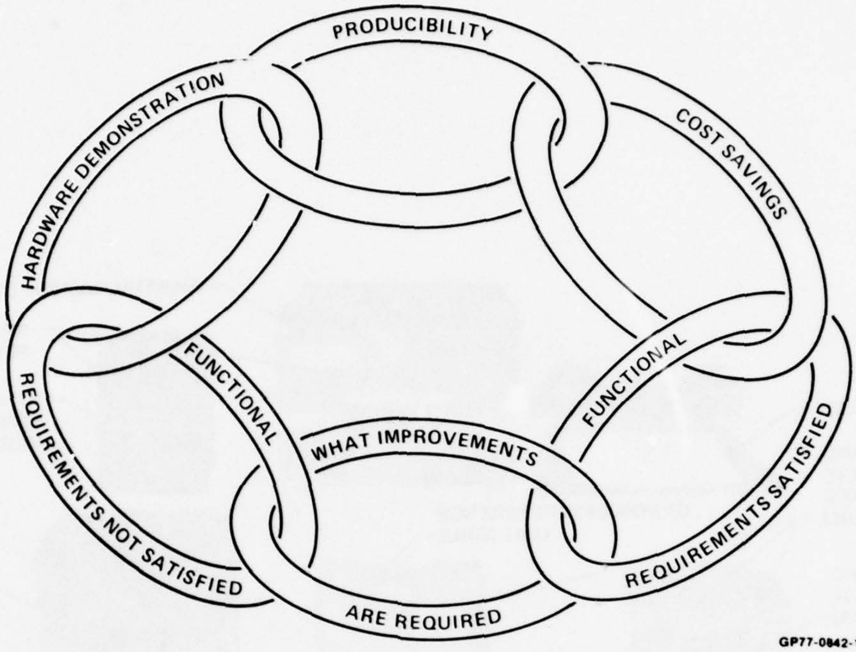


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**FIGURE 14**
**PRELIMINARY FEASIBILITY ASSESSMENT CRITERIA**

- **DETERMINE CONVENTIONAL AVIONICS TO BE REPLACED OR AFFECTED BY MIRA**
- **SELECT A REPRESENTATIVE BASELINE MIRA CONFIGURATION**
- **SELECT A COST MODEL FOR EACH ELEMENT OF COSTS**
  - R&D (DEVELOPMENT)
  - INVESTMENT (PRODUCTION)
  - O&S (DEPLOYMENT)
- **PERFORM COST PREDICTIONS FOR THE CONVENTIONAL AND MIRA AVIONICS LIFE-CYCLE-COST AND DETERMINE THE POTENTIAL SAVINGS**
- **CONDUCT FIGHTER COST STUDY IN PARALLEL WITH TRANSPORT COST STUDY**

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**FIGURE 15**
**LIFE-CYCLE-COST FEASIBILITY STUDY APPROACH**

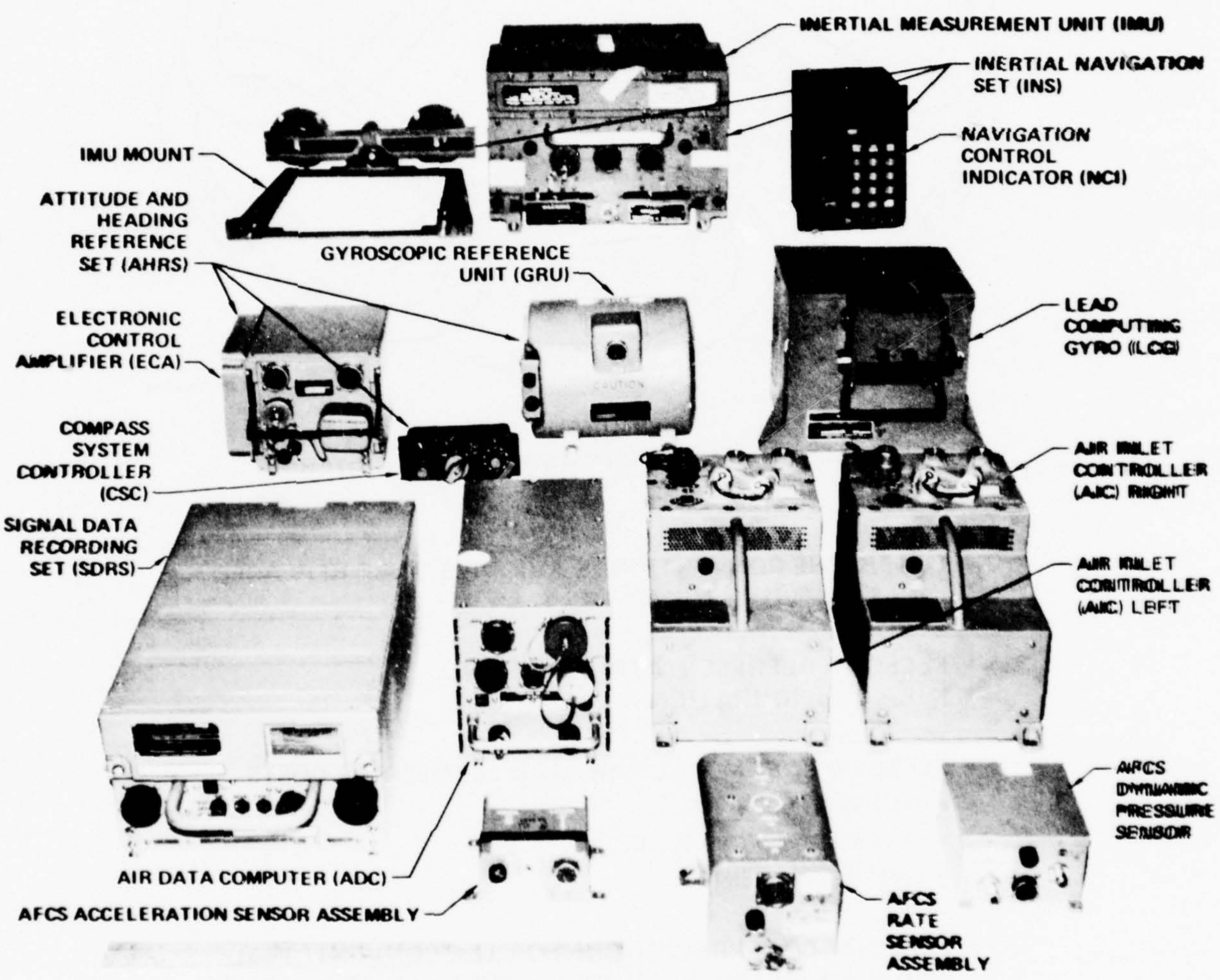


FIGURE 16
F-15 EQUIPMENT IMPACTED BY MIRA

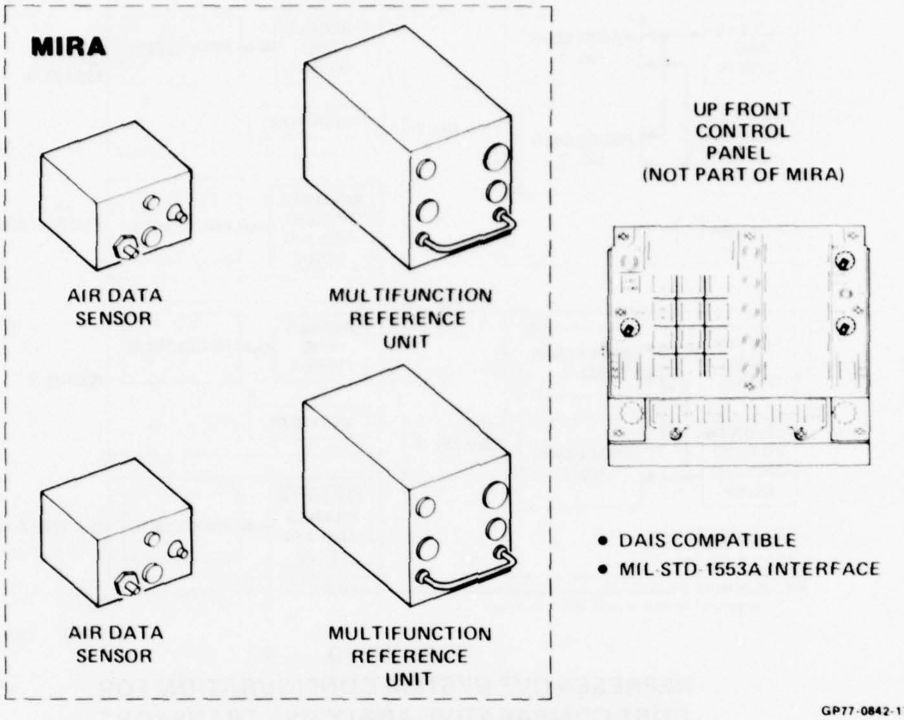


**FIGURE 17**
**REPRESENTATIVE SYSTEM CONFIGURATION FOR COST COMPARATIVE ANALYSIS - FIGHTER**

| COST ELEMENT | CONVENTIONAL (159.3 LB) AVIONICS | MIRA | |
|---|---|---|---|
| | | 50 LB (MIN) | 60 LB (MAX) |
| R&D | 30 | 17 | 18.5 |
| INVESTMENT | 60 | 29 | 32.0 |
| O&S* | 95 | 59 | 65.5** |
| TOTAL | 185 | 105 | 116.0 |
| MIRA COST SAVINGS | N/A | 80 | 69.0 |

Note (1) All numbers are in millions of 1 Jan. 1977 dollars.
(2) 200 systems, 144 aircraft, 15 year operational life
(3) Technology based on 1985 aircraft go-ahead

*O&S includes investment support costs because PRICE investment does not include investment support

**Approximated from ratio of investment costs

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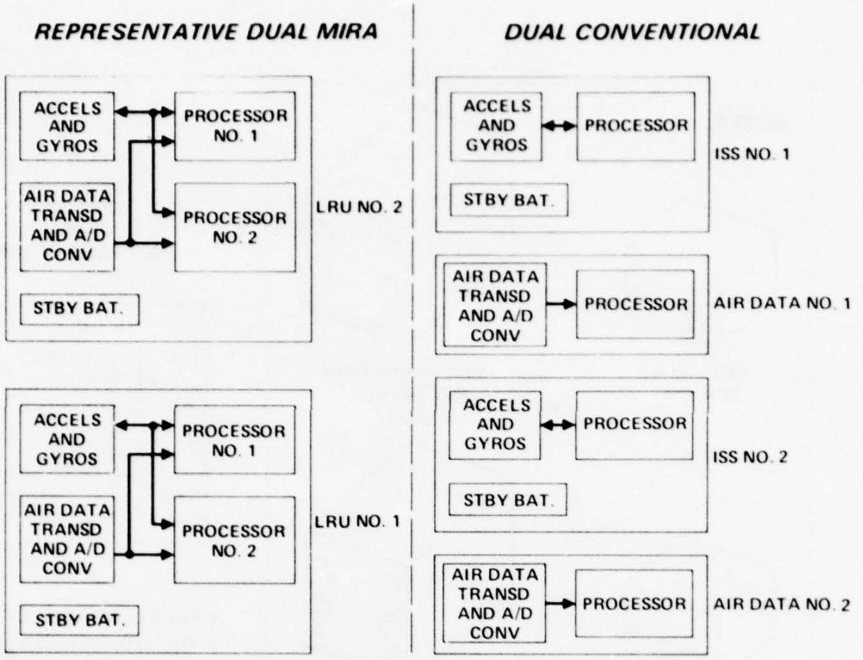
**FIGURE 18**
**COST COMPARISON - FIGHTER**




Note: Dual MIRA is functionally more reliable than dual conventional MIRA due to dual processing of inertial and air data in each MIRA processor.

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**FIGURE 19**
**REPRESENTIVE SYSTEM CONFIGURATION FOR COST COMPARATIVE ANALYSIS - TRANSPORT**

| SYSTEM | COST |
|---|---|
| MIRA | $223,000 |
| CONVENTIONAL | $224,000 |
| COST SAVINGS | $1,000 |

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**FIGURE 20**
**EQUIPMENT PRODUCTION COST COMPARISON - TRANSPORTS**

| | PRESENT CAPABILITY | REQUIREMENT |
|---|---|---|
| • POSITION ACCURACY | 2-3 NM/HR | 1 NM/HR |
| • VELOCITY ACCURACY | 8-10 FPS | 2-3 FPS |
| • ASSOCIATED REDUNDANCY | FURTHER INVESTIGATION UNDER DYNAMIC CONDITIONS | |

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**FIGURE 21**
**PERFORMANCE IMPROVEMENT REQUIRED**

| EQUIPMENT | MTBF (HRS) |
|---|---|
| CURRENT | 67.0 |
| MIRA | 760.0 |
| IMPROVEMENT GOAL = 11.3 | |

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**FIGURE 22**
**RELIABILITY IMPROVEMENT REQUIRED**

*DESIGN*

- CONTRACTUAL LIMITATION OF COMPONENT STRESS LEVELS
- IMPROVED THERMAL DESIGN
- IMPROVED PART APPLICATION
- FEWER COMPONENTS - ELIMINATE GIMBALS, USE OF LSI MICROPROCESSORS
- RELIABILITY DEVELOPMENT TESTING
  - DESIGN LIMIT ENVIRONMENTAL EXTREMES
  - REALISTIC DUTY CYCLES TO MATCH MISSION PROFILES
  - ACCUMULATE EQUIVALENT SERVICE LIFE

*MANAGEMENT*

- IMPROVED PARTICIPATION DURING EARLY DESIGN PHASE
- INCREASED FUNDING FOR EARLY TESTING
- EQUIPMENT DESIGNERS TASKED WITH SPECIFIC RELIABILITY REQUIREMENTS
- IMPROVED CORRELATION OF LABORATORY AND FIELD RELIABILITY MEASUREMENT GROUND RULES
- CONTINUOUS AND AGGRESSIVE FOLLOW-UP THROUGHOUT LIFE OF PROGRAM

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**FIGURE 23**
**METHODS OF ACHIEVING RELIABILITY IMPROVEMENT**


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**FIGURE 24**
**HONEYWELL LABORATORY DEMONSTRATION**
(Ring Laser Gyro - 1 Tetrad Cluster)

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FIGURE 25
SINGER-KEARFOTT LABORATORY DEMONSTRATION
(Tuned Rotor Gyro - 2 Skewed Clusters)

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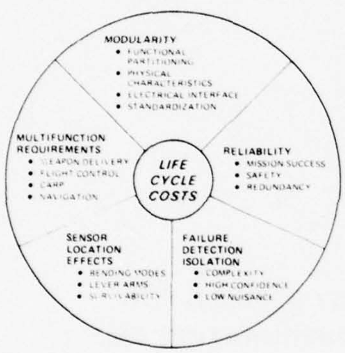
**FIGURE 26**
**LITTON LABORATORY DEMONSTRATION**
(Tuned Rotor Gyro - 2 Skewed Clusters)

MIRA KEY ISSUES




| KEY ISSUE | PRELIMINARY ASSESSMENT OF FEASIBILITY |
|---|---|
| MULTI-FUNCTION REQUIREMENTS | FUNCTIONAL OUTPUTS OF INERTIAL POSITION, VELOCITY, ACCELERATION, RATES AND AIR DATA CAN BE OBTAINED. TECHNOLOGY IMPROVEMENTS WILL IMPROVE POS AND VEL ACCURACY IN THE NEAR FUTURE |
| SENSOR LOCATION EFFECTS | CONTROL LAWS CAN BE MODIFIED TO ACCOMMODATE USE OF PHYSICALLY SEPARATED MRU LRUs |
| FAILURE DETECTION AND ISOLATION | DEMONSTRATED IN LAB FOR HARD OVER, SLOW OVER AND SOFT OVER FAILURES WITH RLG AND TRG |
| RELIABILITY | REDUNDANT AND SKEWED SENSORS AND CLUSTERS PROVIDED ADEQUATE MISSION AND SAFETY OF FLIGHT RELIABILITY |
| MODULARITY | MIL-STD-1553A MUX CAN BE USED. INERTIAL/AIR DATA FUNCTIONS CAN BE INTEGRATED AND STANDARDIZED |
| LIFE-CYCLE-COST | FIGHTER SAVINGS: \$69 - \$80 M̄ TRANSPORT SAVINGS: QUALITATIVELY SIGNIFICANT |

GP77-0842-27

**FIGURE 27**
**KEY ISSUES RESULTS**

- MIRA FEASIBILITY HAS BEEN ESTABLISHED
- MIRA PROVIDES SIGNIFICANT COST SAVINGS AND MERITS CONTINUED DEVELOPMENT
- MIRA PERFORMANCE CAPABILITY WILL BE ADEQUATE FOR FIGHTER AND TRANSPORT
- RELIABILITY AND MAINTAINABILITY REQUIREMENTS WILL BE MET
- AIR DATA COMPUTATION SHOULD BE PART OF MIRA
- SUPPLEMENTAL DEMONSTRATION EFFORT TO EVALUATE MIRA VELOCITY, ACCURACY AND REDUNDANCY UNDER DYNAMIC TRANSLATION CONDITIONS DURING PHASE I WILL PROVIDE ADDED KEY INFORMATION

GP77-0842-28

**FIGURE 28**
**OVERALL CONCLUSIONS - TASK I**

- CONTINUE MIRA FEASIBILITY STUDY (PHASE I) FOR DEVELOPMENT OF FINAL MIRA CONFIGURATION AND PREPARATION OF SPECIFICATION
- INITIATE A SUPPLEMENTAL TEST TO DEMONSTRATE PERFORMANCE ON SOFTWARE REDUNDANCY USING LAB HARDWARE ON A MOVING VEHICULAR TEST BED
- BEGIN DETAIL PLANNING FOR MIRA PHASE II ADP FLIGHT TEST

GP77-0842-29

**FIGURE 29**
**RECOMMENDATIONS - TASK I**

BRIEFING TITLE

AIRLINES DEVELOPMENT - LTN-72 INS

DICK PERRIN

LITTON AERO PRODUCTS DIVISION
WOODLAND HILLS CA

808005

PRESENTATION FOR 11th ANNUAL
JOINT SERVICES EXCHANGE
FOR INERTIAL SYSTEMS

OCTOBER 1977

by

R. J. PERRIN

for

Department of the Air Force
HQ. Aerospace Guidance
and Metrology Center
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Ohio 43055

Litton AERO PRODUCTS

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ACKNOWLEDGEMENT

I would like to express my indebtedness to John Hayward of Aero Products Technical Publications who compiled the data for and wrote the Support Services section of this paper as well as helped with the technical section.

Dick Perrin

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The LTN-72,

or,

How I Came to Love Commercials (Inertials That Is)

The LTN-72 is a compact, lightweight, second generation, ARINC-561 inertial navigation system designed to fulfill the navigation requirements of modern transport type aircraft. As shown in Figure 1, it consists of three units, the Inertial Navigation Unit (INU), the Control/Display Unit (CDU), and the Mode Selector Unit (MSU).

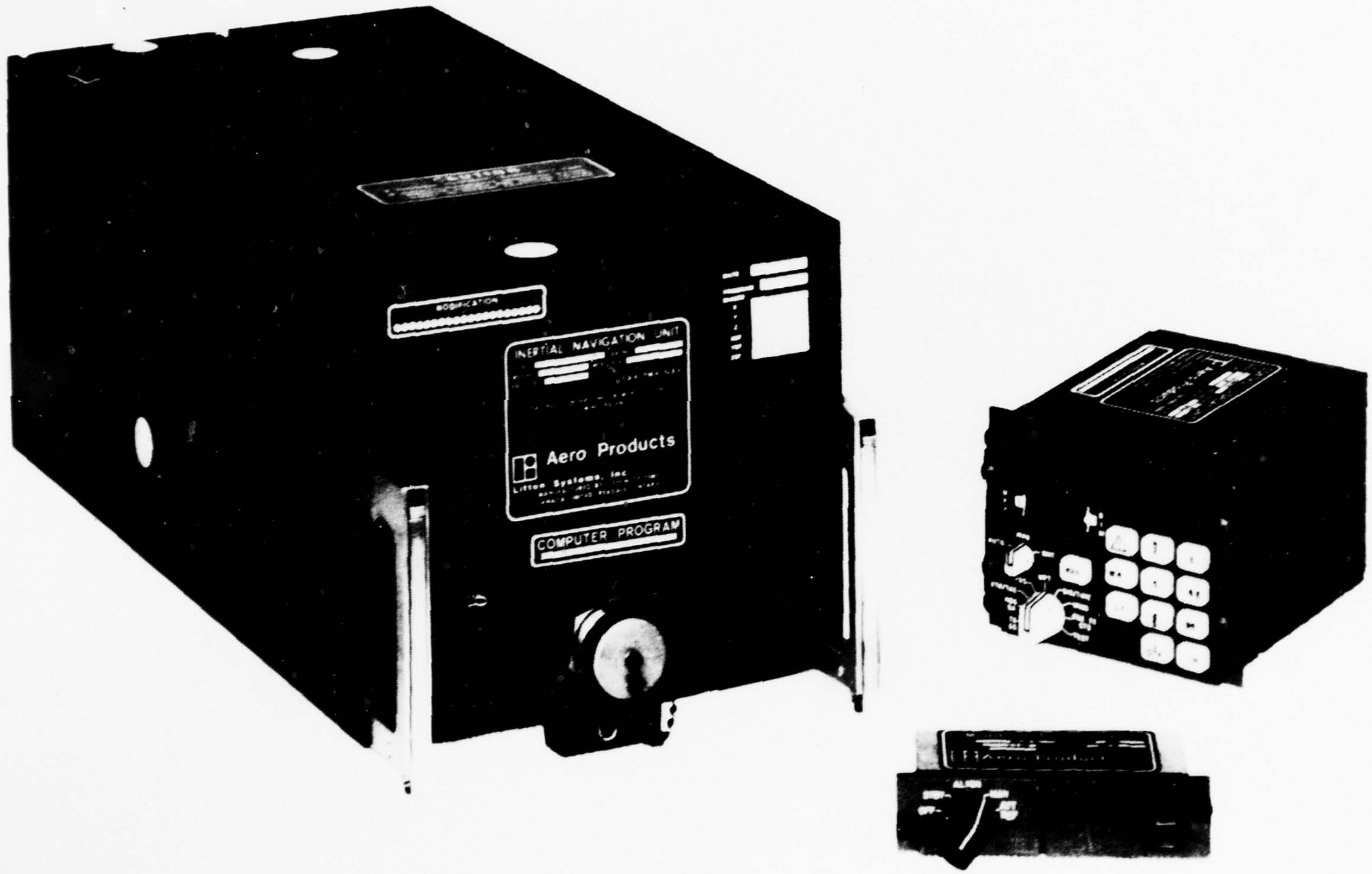
The INU (Figure 2) contains a four gimbal platform, platform electronics, the digital computer, all aircraft interface electronics, and a power supply. In short, it is about 95 percent of the system, which makes flight line or "0" level maintenance an easy task.

The CDU (Figure 3) is essentially a digital data transmitter, receiver, a group of switches and annunciators for data exchange with the computer in the INU. The MSU is simply a switch and two annunciators.

Integration in an aircraft is as shown in Figure 4. Note the INS components in the lower center. The pitch and roll outputs provide high accuracy ($\pm 0.5^{\circ}$) non-pendulous attitude to the ADI. The HSI receives true heading, desired track, To/From, cross track deviation, track, distance to next waypoint, and the appropriate flags. The CDU provides digital presentations of the same data plus present position, waypoints, wind, ground speed, drift angle, desired track angle and system status.

The INU inputs power, including a backup battery dc, and true airspeed. Additional attitude outputs are available for radar, autopilot, doppler, etc.

# LTN-72 INERTIAL NAVIGATION SYSTEM

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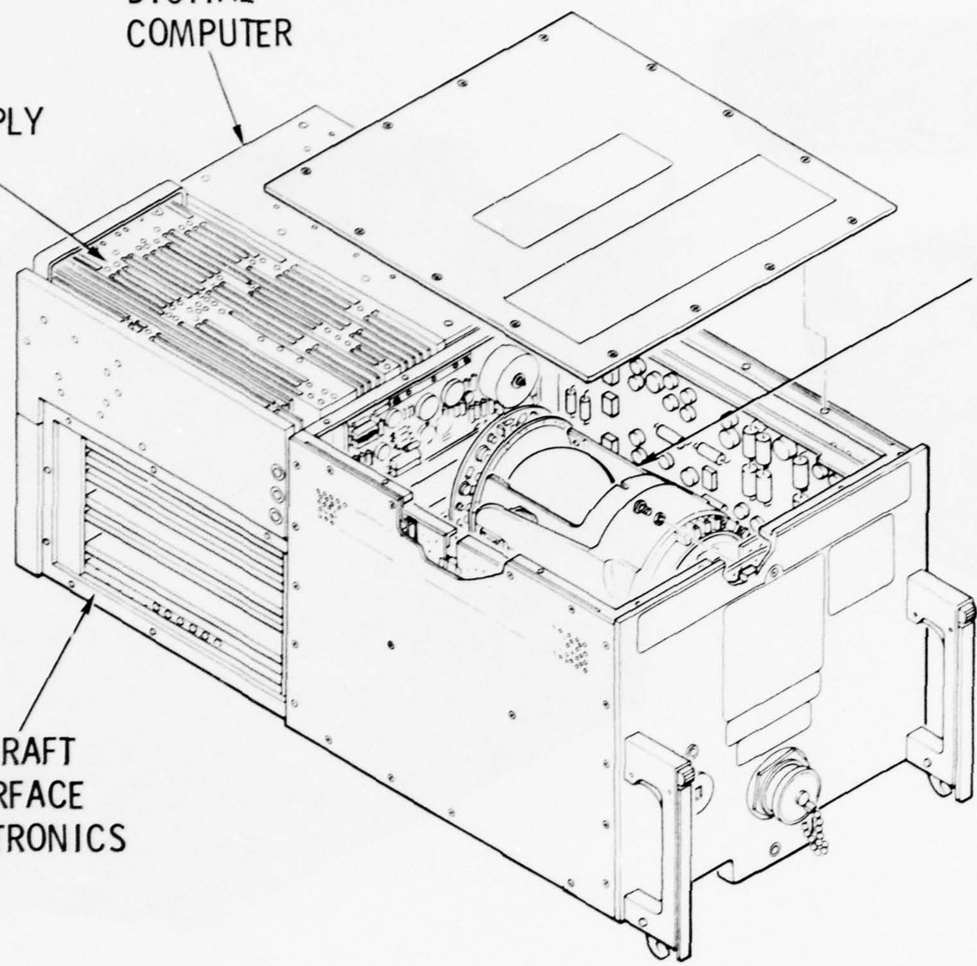
# LTN-72 INU

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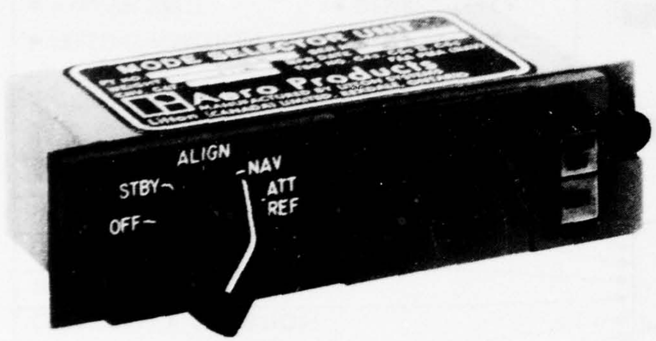
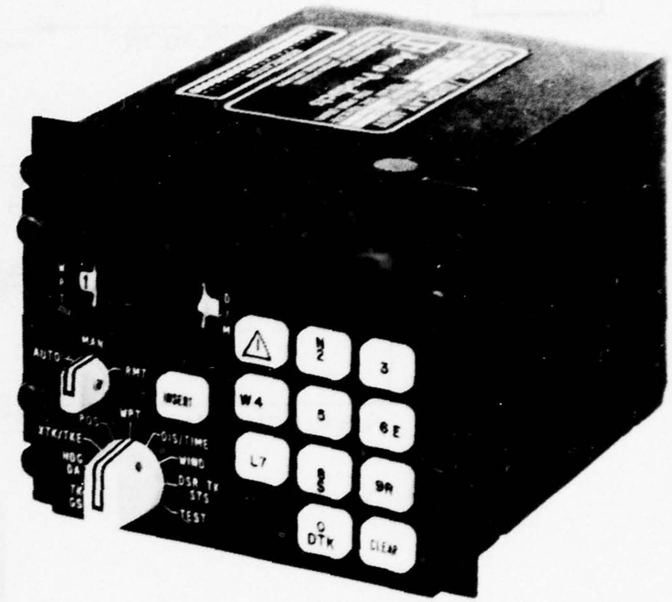
**LTN-72 MSU** **LTN-72 CDU**

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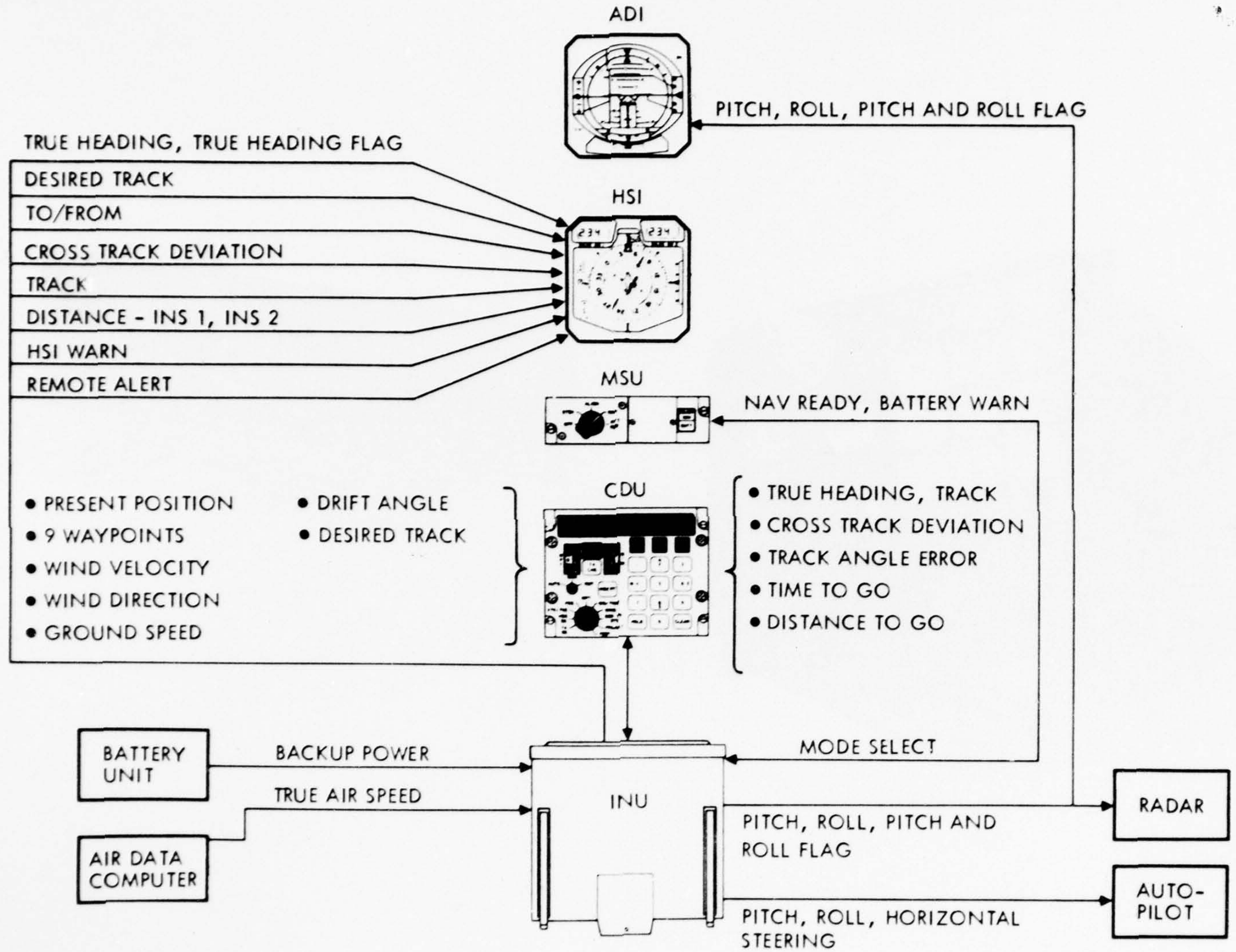
# LTN-72 INTEGRATION DIAGRAM




808005-1

Some of the key features of the LTN-72 are:

- Cantilevered gimbal platform with integral servo electronics (Figure 5)

  Restoring and servo amplifiers are mounted as close to the signal source as possible to reduce slip ring requirements. Flex leads are used in the redundant inner roll gimbal and in pitch which, because of the flipping characteristic, can give full 360° acrobatic capability with ±90° of freedom. Instruments are removed and replaced in minutes using three hand tools without removing the gimbal set from the INU.

  NOTE: Transverse mounting is optional, allowing the INU to be mounted athwartships instead of longitudinally.

- Dry vibragimbal tuned rotor gyros (Figure 6)

  The high accuracy design yields a random gyro drift rate of 0.003 deg./hr 1$\sigma$.

  Require less than half the parts of a conventional gyro. Gimbals rotate along with inertia ring, cancelling mass unbalance effects normal to the spin axis.

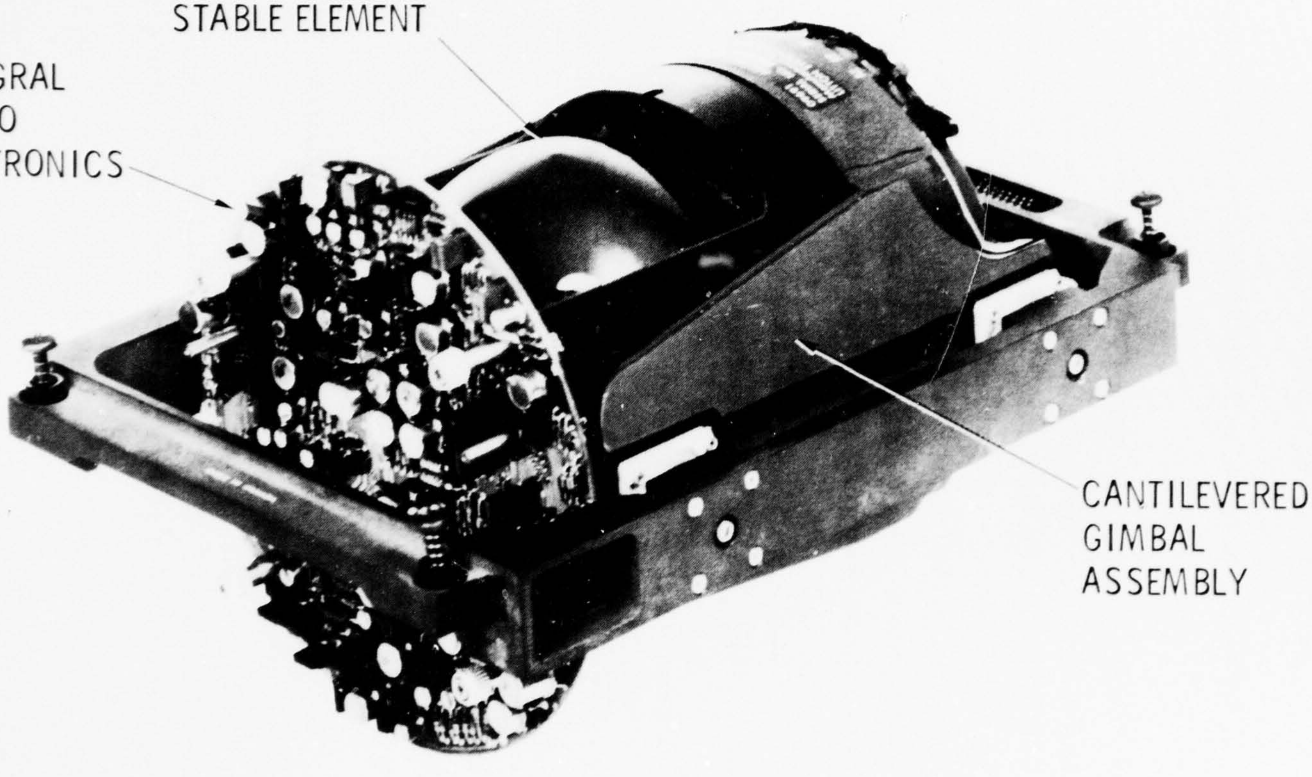
  Pivots and jewels are replaced by torsion bars, eliminating friction effects.

  Absence of flotation fluid eliminates filling and bubble problems and reduces volume and temperature sensitivity.

- Dry, flexure-supported accelerometers (Figure 7)

  Extremely small, simple, and lightweight, they have only 22 parts.

# CANTILEVERED GIMBAL PLATFORM WITH INTEGRAL SERVO ELECTRONICS

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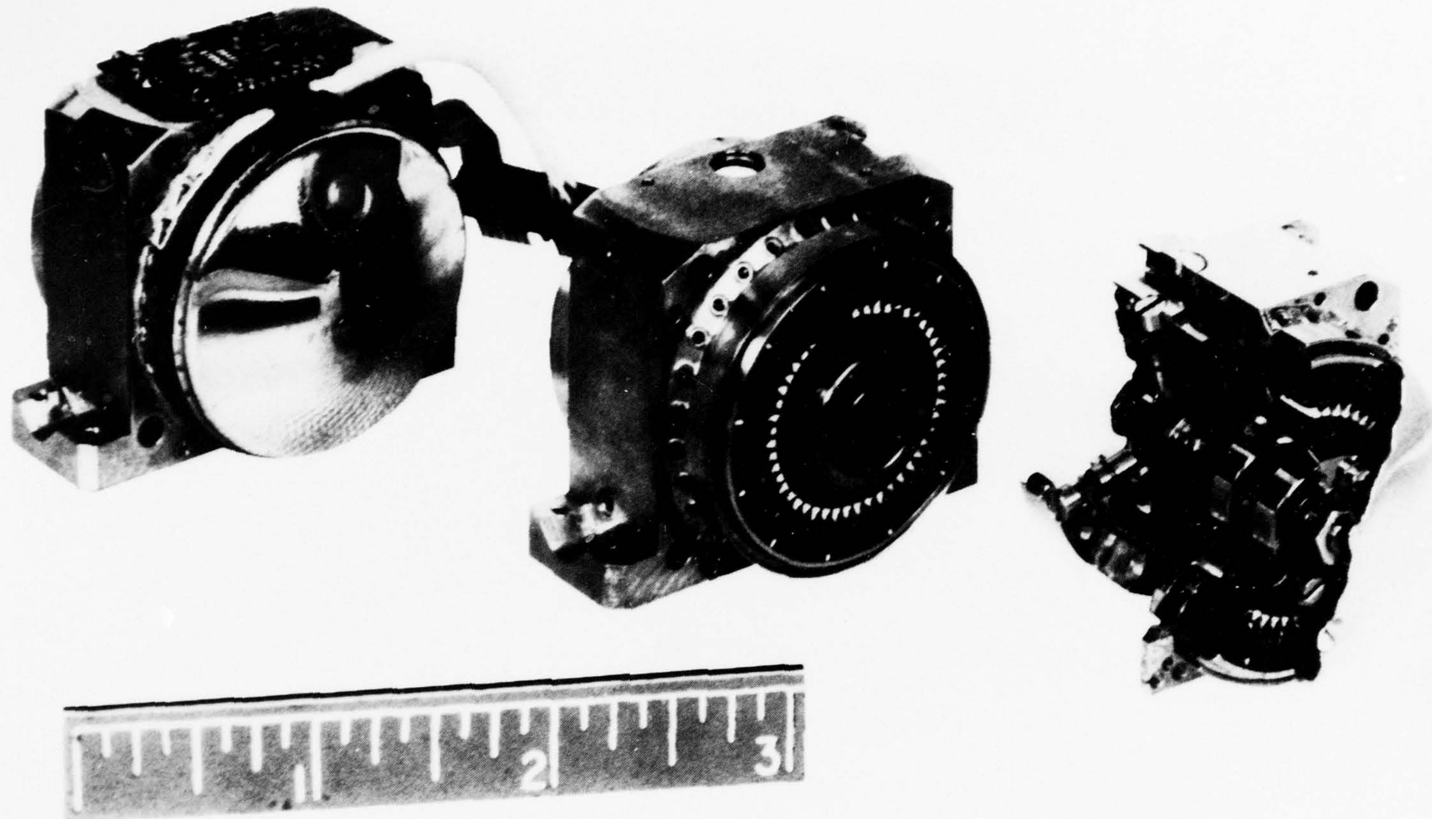
C-8672-C

# VIBRAGIMBAL TUNED ROTOR GYROS

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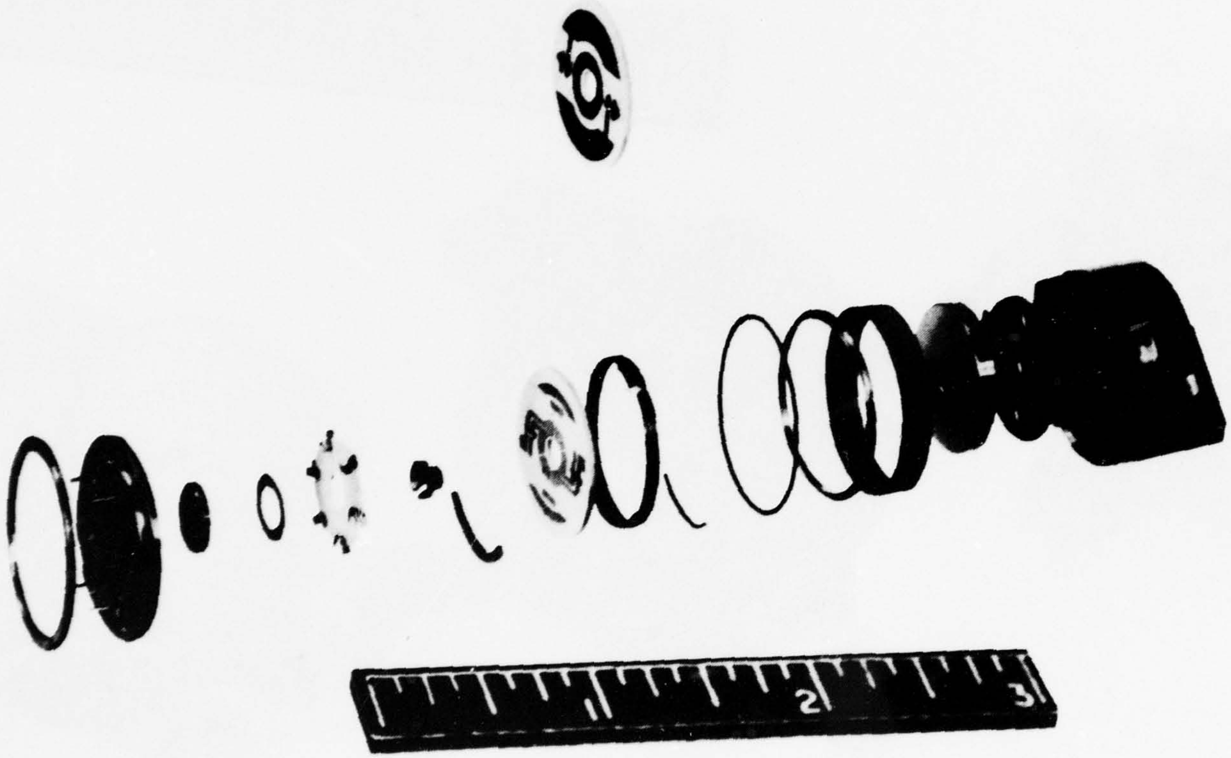
# DRY, FLEXURE SUPPORTED ACCELEROMETERS



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A-5171-B

Single printed pattern forms capacitive pickoff plates, circuitry, and flexure.

Absence of flotation fluid eliminates filling and bubble problems and reduces temperature sensitivity.

- Malfunction and action codes, Built In Test Equipment (BITE) Indicators (Figure 8)

  Monitoring gives nonambiguous annunciation of more than 95 percent of all failures.

  Computer test operations are performed automatically in line with the INS program. Failure of a test causes CDU display of one of 7 action codes and one of 20 malfunction codes.

  A monitor module provides 6 BITE indicators which individually, or in combination, signal 10 failures.

  The power supply has 3 additional BITE indicators monitoring its major sections.

- High speed parallel general purpose computer (Figure 9)

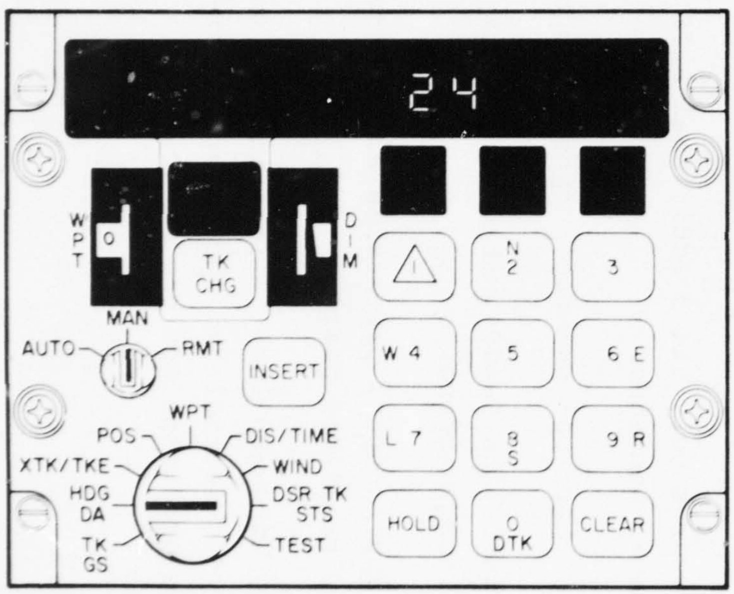
  Designated the C-4000, the computer is a 24 bit, parallel, fractional machine.

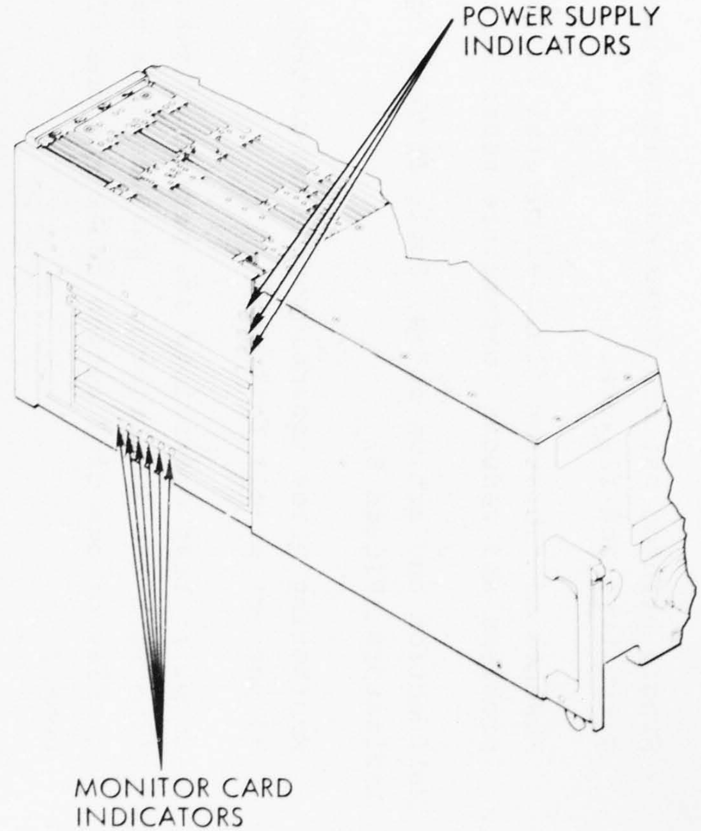
  All input/output, processing and control are housed on seven, two-sided boards.

  The 40 hardware instructions include multiply, divide, binary-to-decimal and decimal-to-binary conversion, and double precision add and subtract.

# MALFUNCTION AND ACTION CODES - BITE INDICATORS

| MALFUNCTION CODES | BITE INDICATORS |
|---|---|




808005-5

AD-A061 615 AEROSPACE GUIDANCE AND METROLOGY CENTER NEWARK AIR FO--ETC F/G 17/7
CONFERENCE PROCEEDINGS OF THE DATA EXCHANGE FOR INERTIAL SYSTEM--ETC(U)
OCT 77 E T BODEM

UNCLASSIFIED AGMC/XR-77-1 NL

2 OF 8
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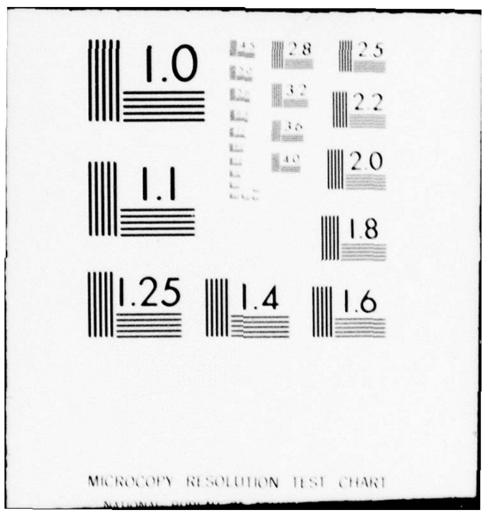
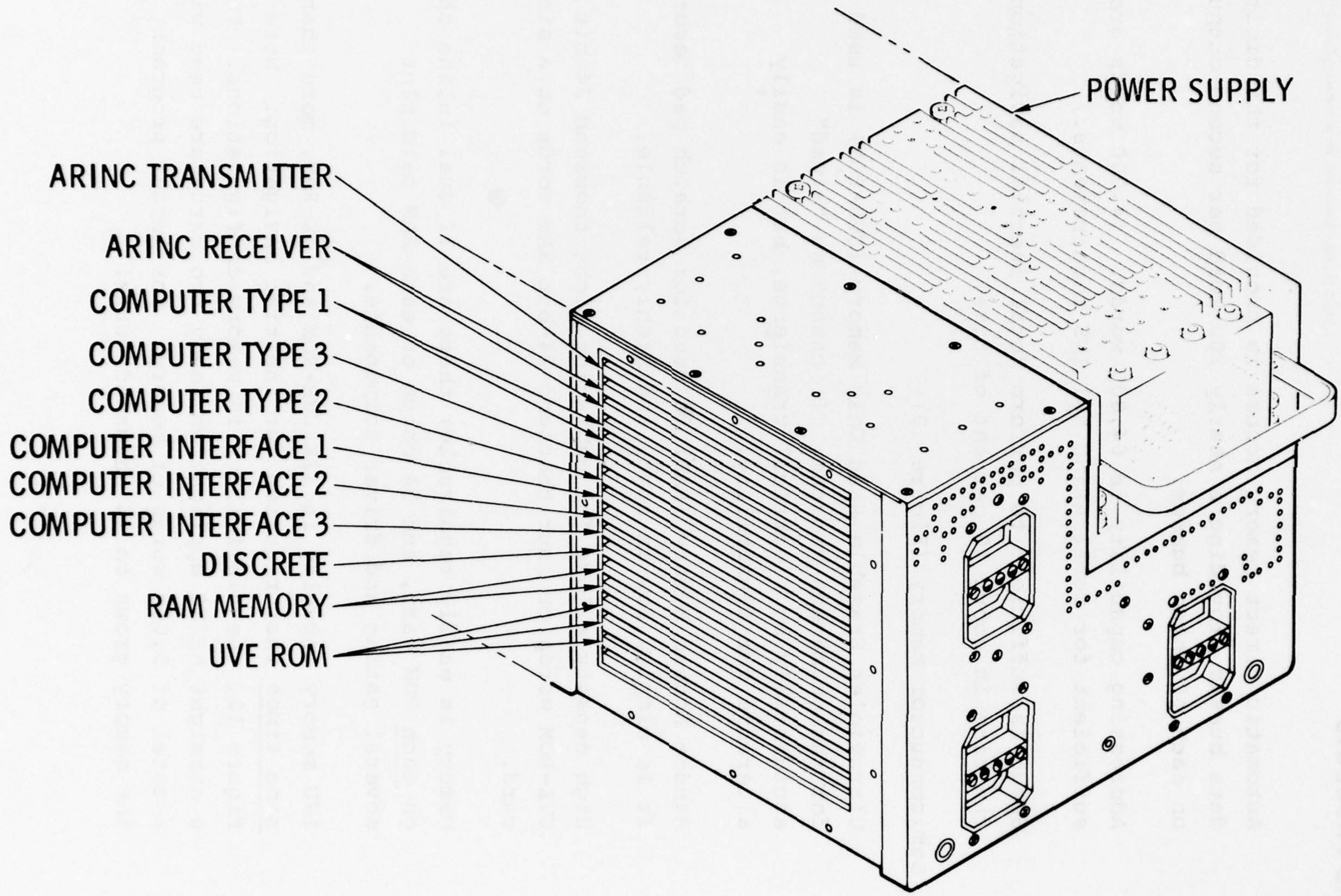
A061 615


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6
MICROCOPY RESOLUTION TEST CHART

# HIGH SPEED PARALLEL GENERAL PURPOSE COMPUTER

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Automatic direct memory access is provided for the digital data busses providing a nearly 200 word per second output on each of three busses.

Addressing capability is 64,000 words. (4,000 words are sufficient for total ARINC 561 INS requirements.)

Speed is sufficient to perform total inertial navigation function in about 10 percent of time.

- Semiconductor memory (Figure 10)

Ultraviolet Erasable Read Only Memory (UVE-ROM) is used for the permanent program. It cannot be "wiped" accidentally by electrical transients, but is easily alterable for flexibility.

Random Access Memory (RAM) is used for scratch pad memory. It is simple, low in cost, and highly reliable.

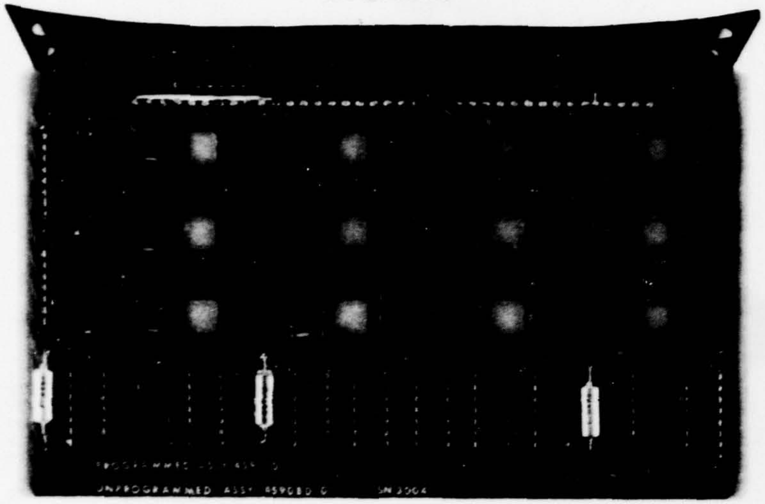
High density allows for packaging eight thousand 24-bit UVE-ROM words or four thousand 24-bit RAM words on a single card.

Memory is easily repairable; there are 12 dual inline chips on each ROM card, and 24 chips on each RAM card plus several gating and driver components.

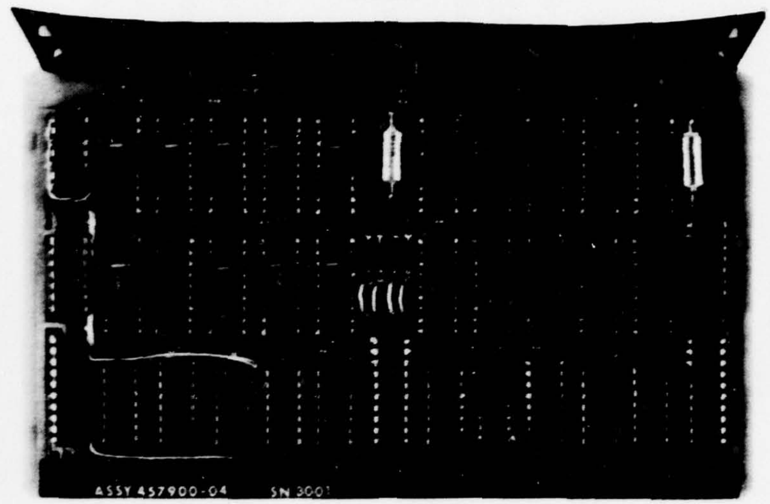
INU memory capacity is 32K UVE-ROM and 4K RAM, more than nine times that required for inertial navigation. Note in Figure 10, the flexibility in memory configurations. For a straight ARINC application, only two cards are used with a total of 5,000 words of memory. For larger programs, the memory grows to 36 thousand words!

# SEMICONDUCTOR MEMORY

UVEROM




RAM




MEMORY CONFIGURATIONS

| | | |
|---|---|---|
| ARINC 561 | 4K ROM | 1K RAM (2 CARDS) |
| EXPANDED | 24K ROM | 8K RAM (5 CARDS) |
| | 32K ROM | 4K RAM (5 CARDS) |

808005-7

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## Expanded Uses

Computer capacity has been emphasized a number of times. Why have nine times the required capacity? It is to provide all manner of extra computational and guidance services - and, there is no cost penalty - because, with modular memory, only the required memory need be resident in any box.

Some of the uses made of the extra capacity are:

- R-NAV (Figure 11) - Inertial position is automatically updated from VOR-DME signals electrically input to the INU. The INU automatically selects the desired station from a catalog entered before or during flight, and auto tunes the receivers. This is certified to FAA Advisory 90-45A for enroute, terminal and approach R-NAV.

  Some users of this extra capacity system are Lufthansa, Australian Department of Transport, Egyptian C-130, U.S. Coastguard, and General Aviation.

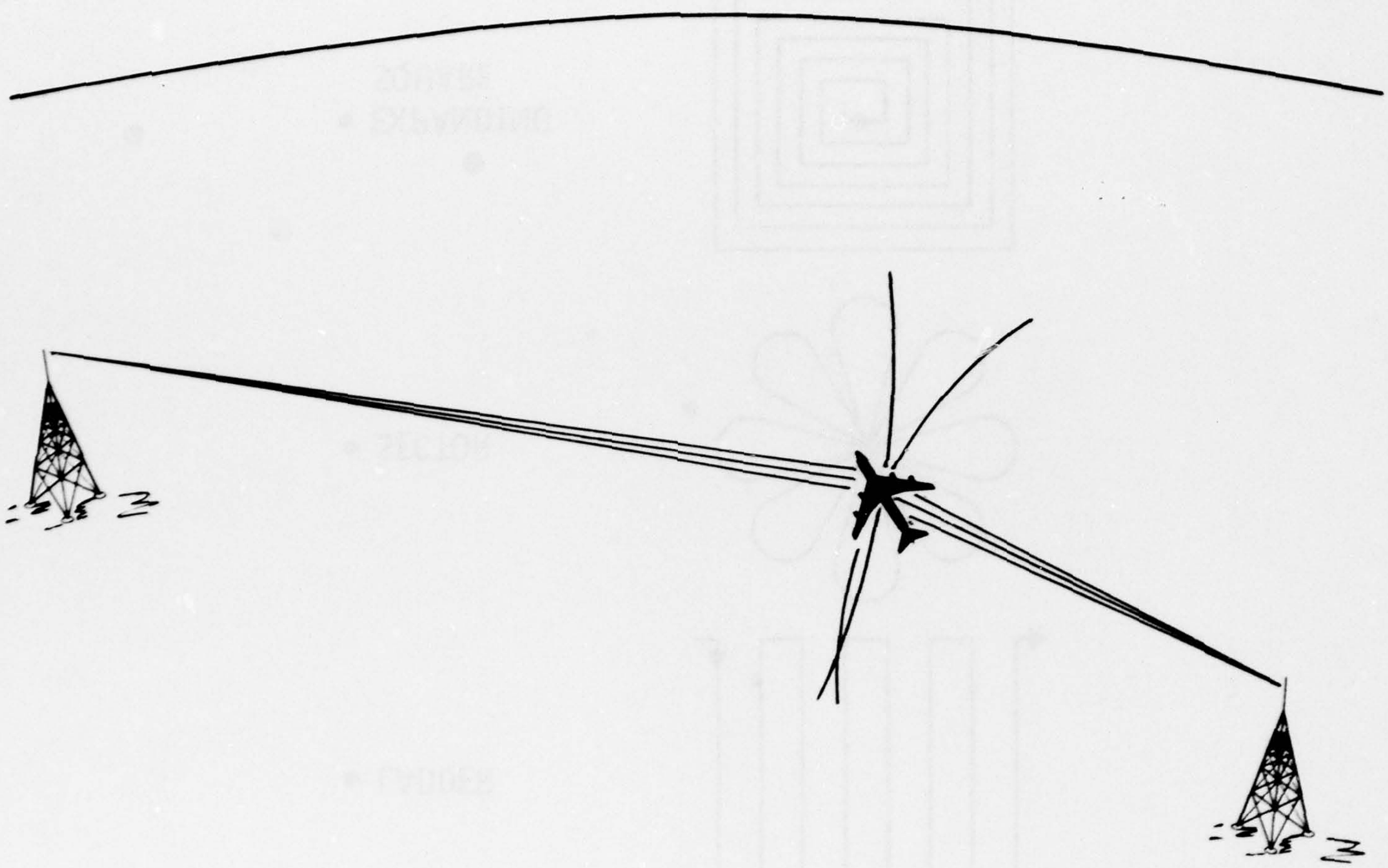
- Search Modes (Figure 12) - Ladder, sector, and expanding square search modes whose parameters are entered at the CDU, are executed automatically with the INS supplying steering signals to the autopilot.

  Users are Australian Department of Transport, Egyptian C-130, Peruvian C-130, U.S. Coastguard.

- LORAN Update (Figure 13) - Similar to R-NAV, the INS position is automatically updated from LORAN master-slave time differences. All LORAN chain data for the world are resident in the INS. Station selection is manual at the LORAN receiver; data are transmitted from the LORAN to the INS via a digital data bus.

  The user is U.S. Coastguard.

# RNAV



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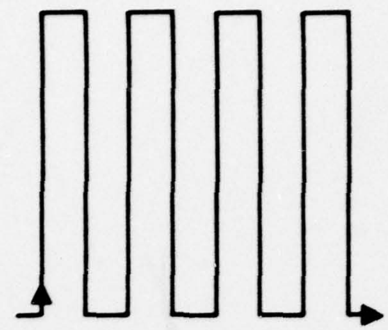
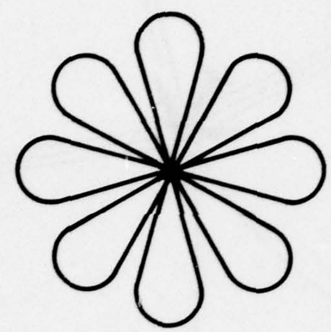
# SEARCH MODES

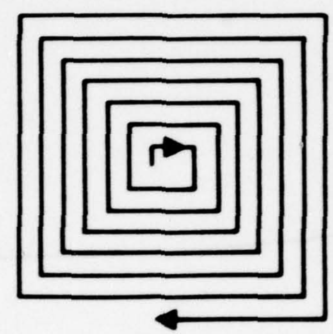
- LADDER



- SECTOR



- EXPANDING SQUARE



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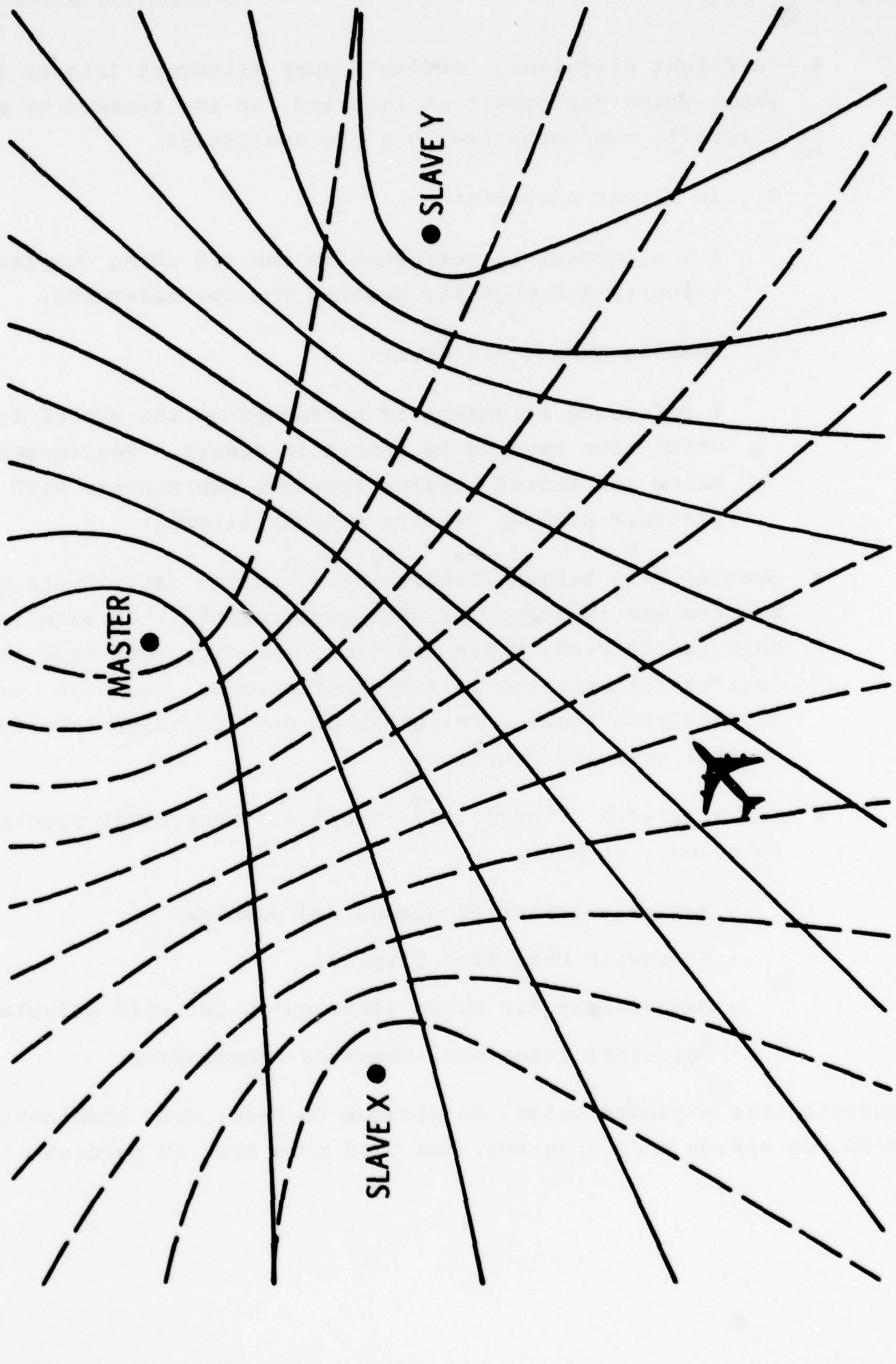
## LORAN UPDATE




808005-10

- In Flight Alignment, Heading Memory Alignment (Figure 14) - Where quick deployment is required, as for tankers or search aircraft, two mechanizations are available:

  1. In Flight Alignment

     INS alignment is performed in the air using doppler velocity and magnetic heading for the reference.

  2. Heading Memory Alignment

     A reference alignment is performed on the ground from which true heading is stored in memory. Realignment using the stored heading requires two minutes with platform preheat or five minutes without.

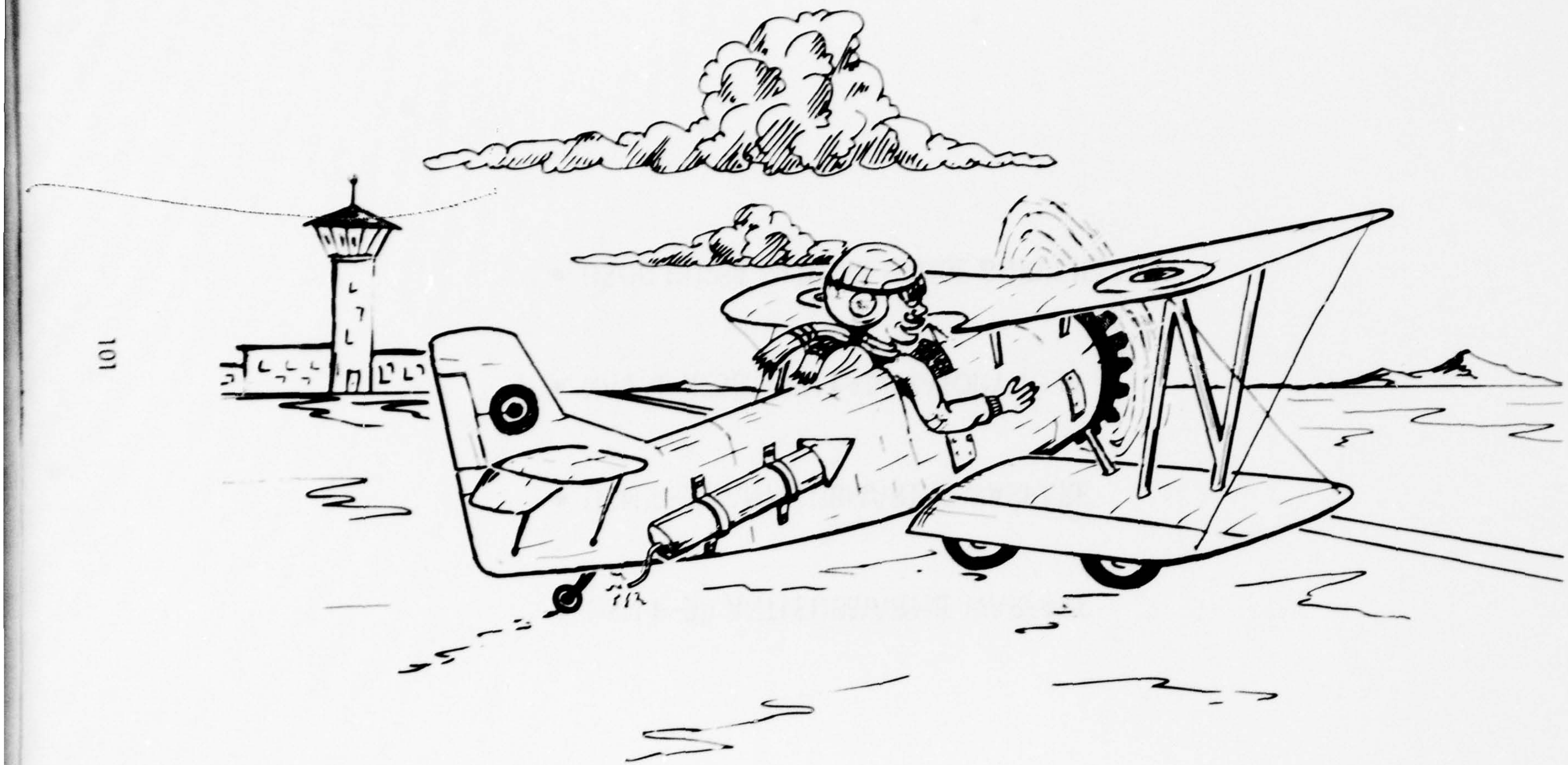
- Special Data Busses (Figure 15) - Digital data inputs and/or outputs are tailored for user requirements. An example of this is the P-3B, where position, velocity, and true heading data are transmitted 24 times per second. The high transmission rate assures freshness of data for high accuracy central computer functions.

- Miscellaneous (Figure 16) - There are many other special functions, such as:

  - Magnetic variation output and display
  - Greenwich Mean Time Display
  - Manual True Air Speed (TAS) entry for wind calculation
  - Universal Transverse Mercator Coordinates

Despite this expanded usage, no program to date, even combination R-NAV or search mode programs, has used more than 50 percent of the

## IN FLIGHT ALIGN,
## HEADING MEMORY ALIGN FAST REACTION



808005-11

# SPECIAL DATA BUSES

- USN P-3B ANTISUBMARINE WARFARE
- USN P-3C ANTISUBMARINE WARFARE
- NAVAL RESEARCH LABORATORY P-3A
- USCG HU25A MEDIUM RANGE SURVEILLANCE

808005-21

# MISCELLANEOUS

- MAGNETIC VARIATION
- GREENWICH MEAN TIME
- MANUAL TRUE AIR SPEED ENTRY
- UNIVERSAL TRANSVERSE MERCATOR COORDINATES

808005-12

computer computational capacity or memory. Additional programs in development are:

- Light Emitting Diode Control Display Unit (LED CDU) (Figure 17) - Programming and circuitry is being developed for a CDU using a 48 x 96 LED array for display instead of 7 segment light bars. The new CDU has only 3 cards of logic instead of 6, yet it can display 5 lines of 16 alphanumeric characters, instead of the present one line of 13 characters.

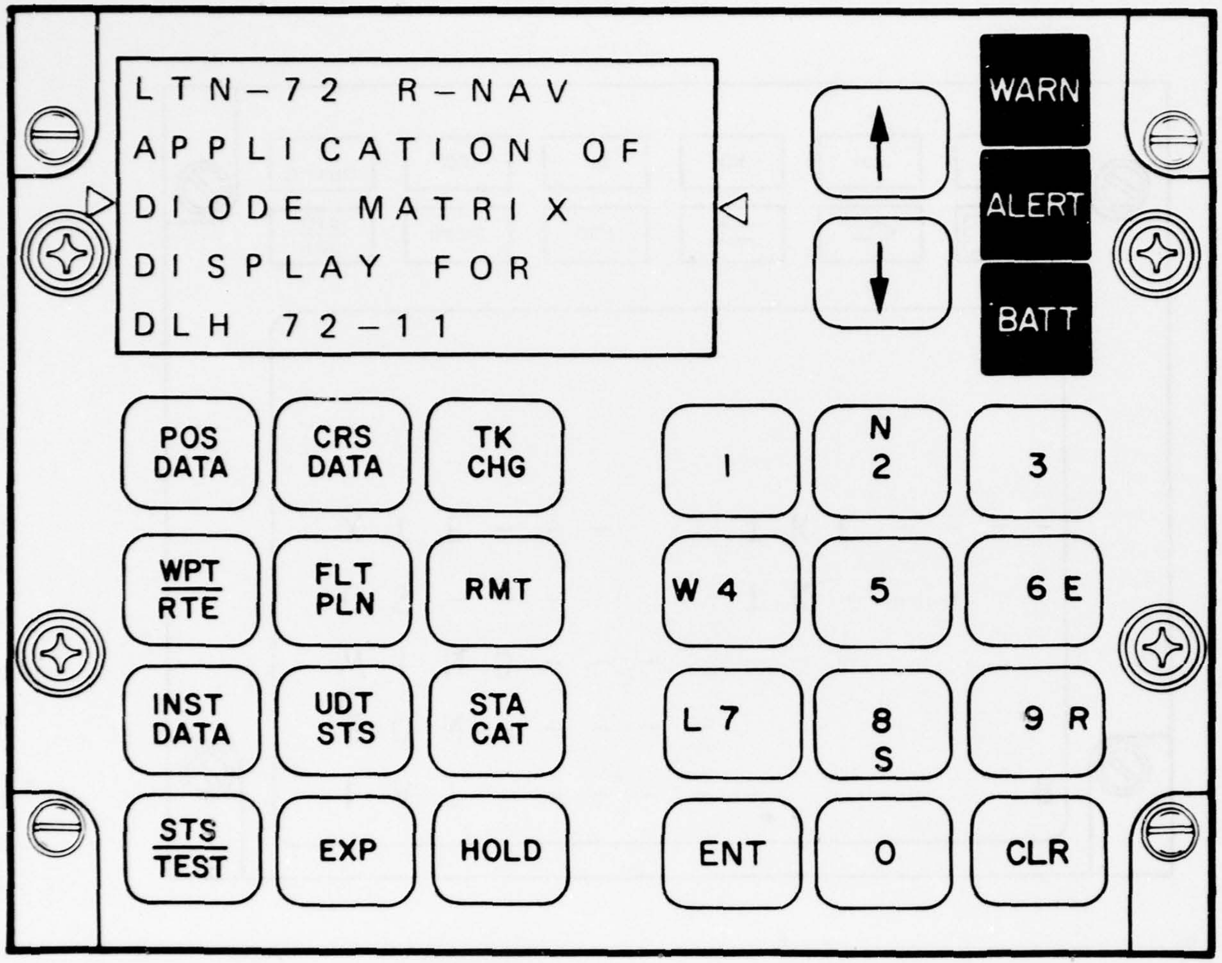
- We have another CDU in the planning stages (Figure 18) - This one uses a 96 x 144 LED array with transparent membrane overlay switches that give almost 12.5 square inches of display and switch area. With this display there will be limited graphics as well as alphanumerics.

- Station Hopping DME Update (Figure 19) - The INS will sequencially autotune a single DME through all available stations, using the corresponding distance data for position fixing. Thus $rho^2$ or $rho^3$ update is possible from a single DME.

- Photogrammetry Horizontal Guidance and Photo Annotation (Figure 20) - INS uses manually inserted "on tops" of prominent land marks for high accuracy lane guidance resulting in minimum overlap, no gap coverage as shown here. INS provides for film annotation (Figure 21) with date, time, heading, drift angle, position, attitude, and altitude on each frame which greatly improves the speed and efficiency of the photogrammetric process.

- Spraying Patterns (Figure 22) - INS provides high accuracy lane guidance similar to photogrammetry. INS output valve turn-on/turn-off signals; and bus data for post flight

# LED CDU

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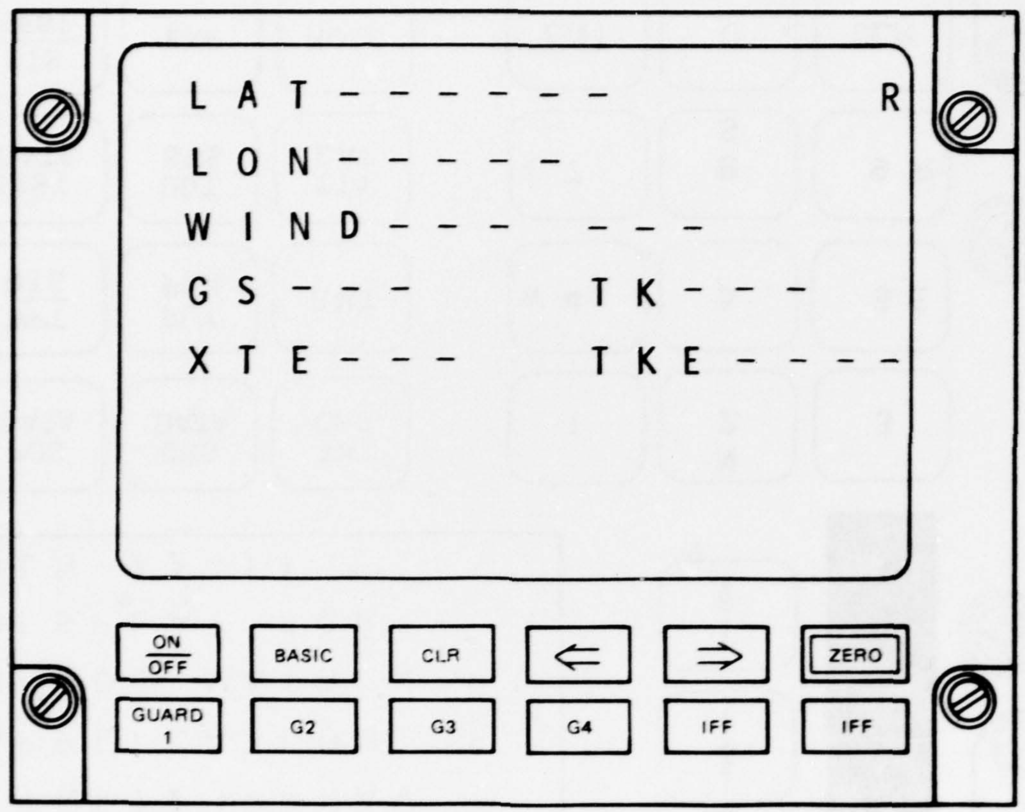
# LED, MEMBRANE SWITCH CDU

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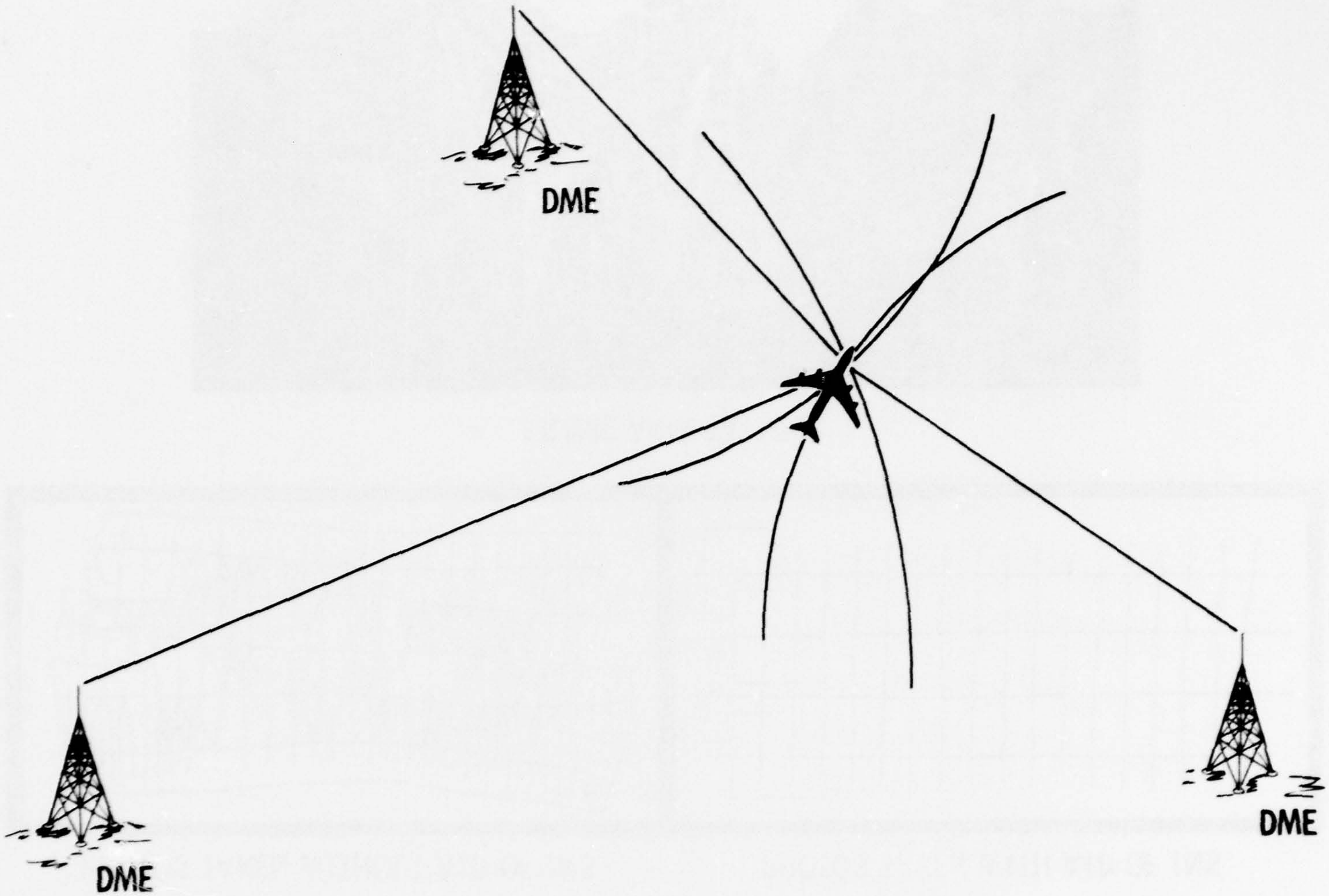
# STATION SCANNING DME UPDATE

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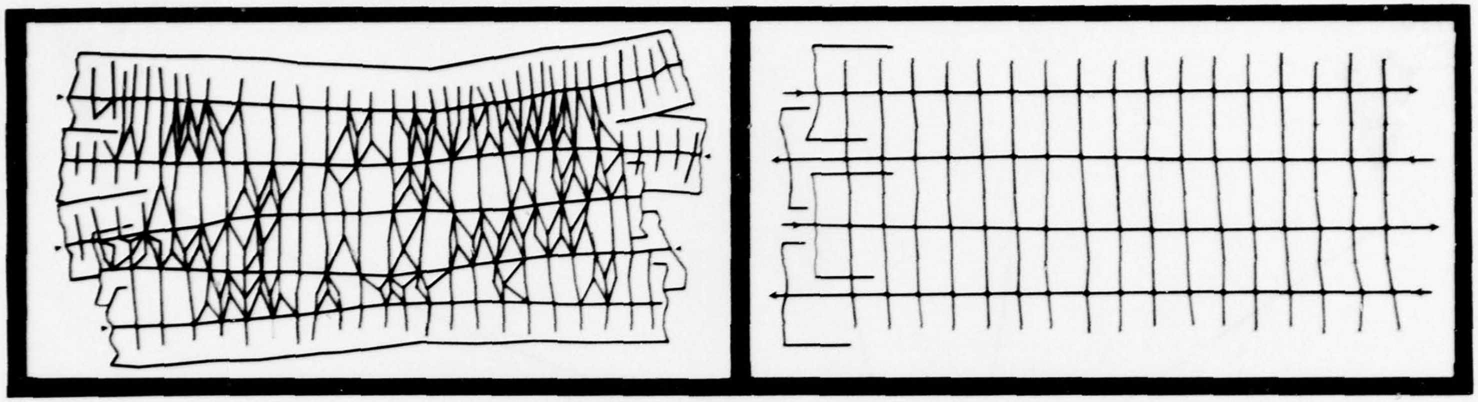
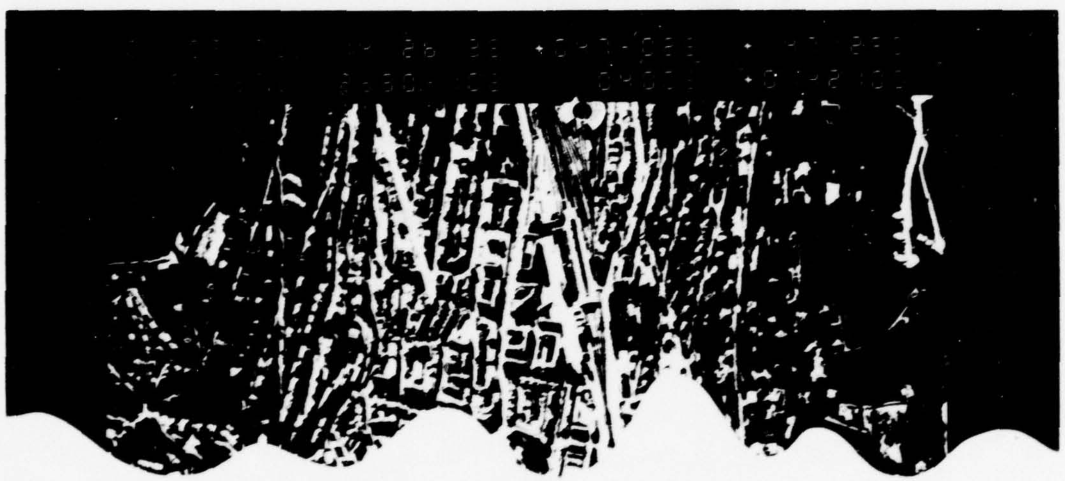
# PHOTOGRAMMETRY HORIZONTAL GUIDANCE WITH PHOTO ANNOTATION

PHOTOS TAKEN WITHOUT AID OF INS

PHOTOS TAKEN WITH AID OF INS



FRAME ANNOTATION



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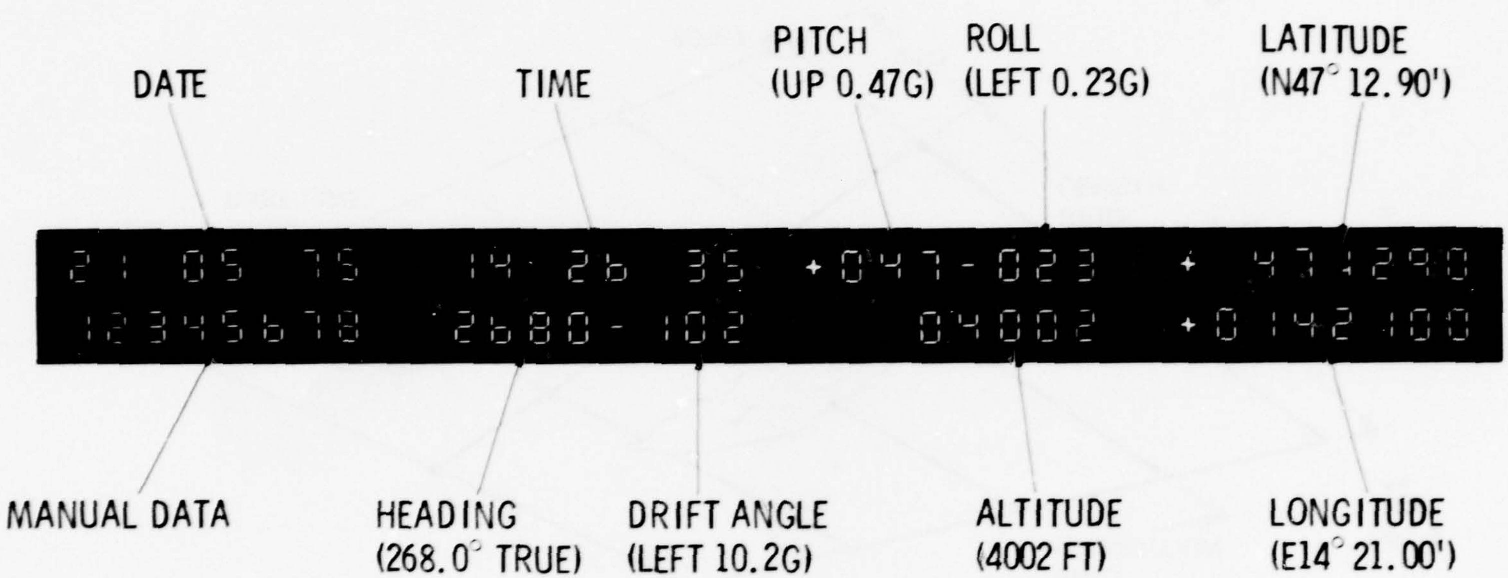
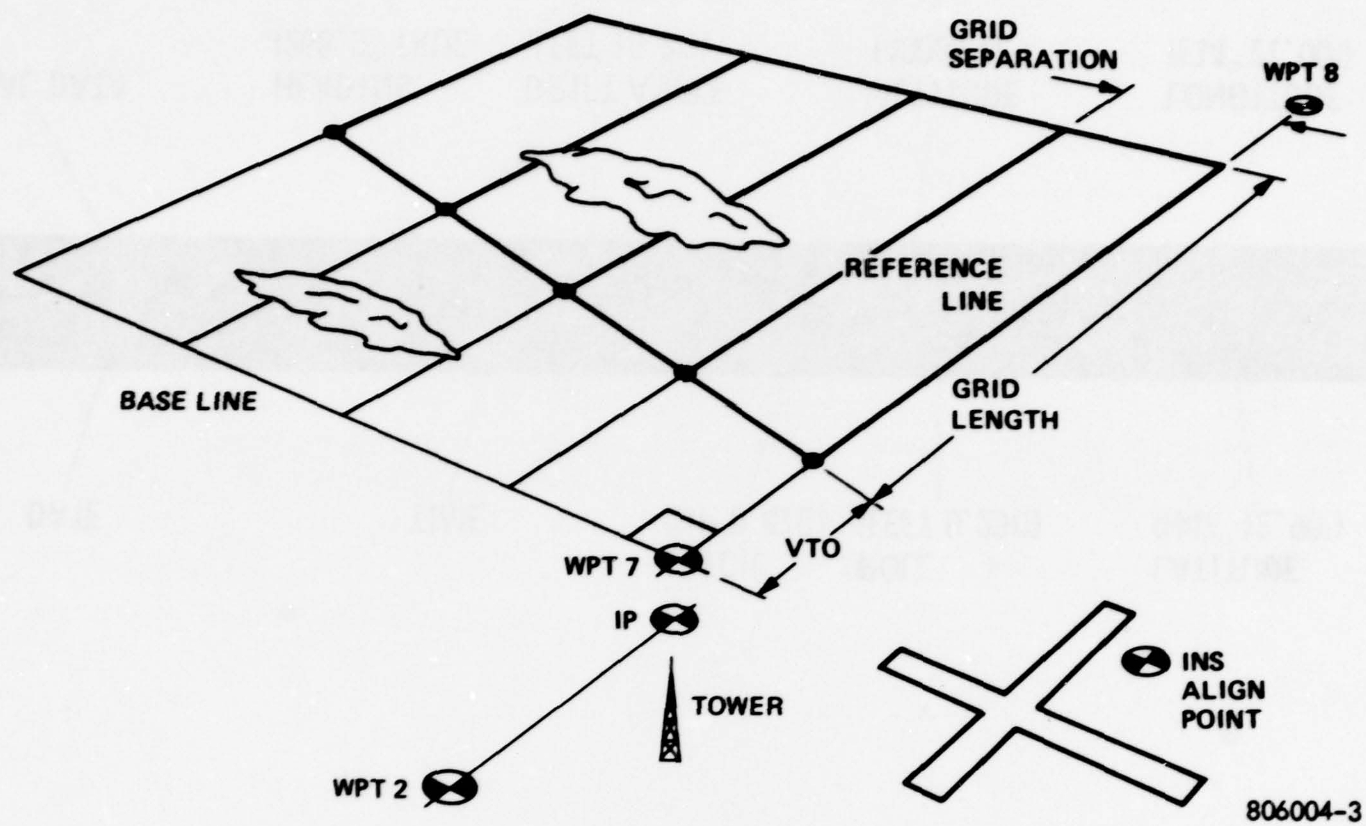
# TYPICAL DATA FORMAT




808005-17

# INERTIAL GUIDANCE GRID



807002-16

reconstruction of sprayed area for record. This aircraft is being guided by our LTN-51; it can spray up to 32,000 acres in a single mission.

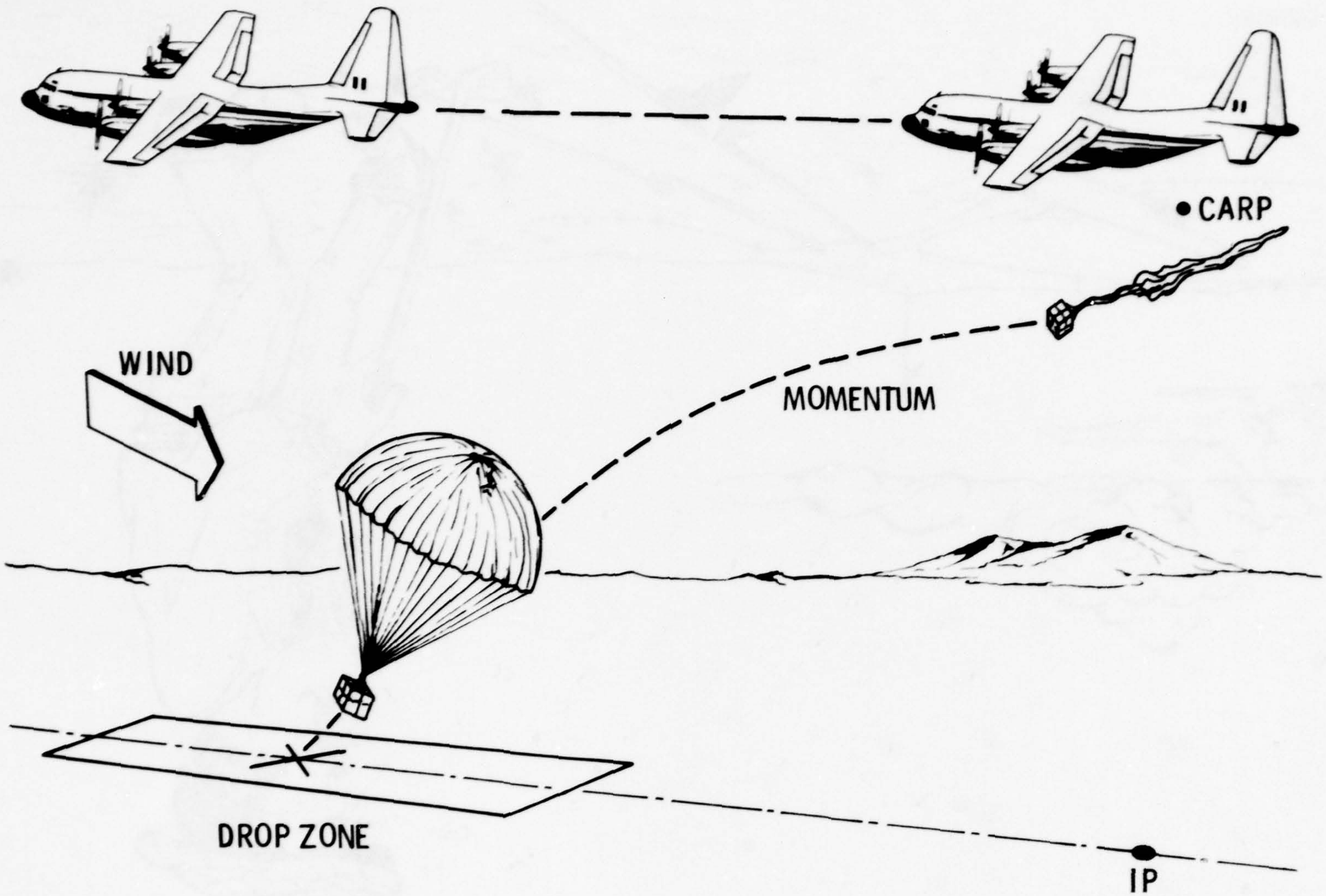
- Computed Air Release Point (CARP) (Figure 24) - Used for accurate air drop of cargo or personnel, the INS uses manual inputs of drop zone position, cargo ballistics, and atmospheric conditions, to compute and steer to the air release point and signal drop interval.

- INS Accuracy Enhancement (Figure 25) - The basic unaided accuracy of the LTN-72 is excellent, but for special requirements, extra calibration models can be incorporated; and Schuler oscillators can be mechanized in the software and used for cancellation of normal errors.

- Flight Inspection (Figure 26) - INS inputs VOR, TACAN or ILS data, compares them with DME updated INS position data (accurate to 0.1 nm through use of station-hopping techniques and multi-state Kalman filter) and outputs radio beam alignment error, course width, symmetry, bends etc. A data multiplex unit is required for interfacing with the many radio devices, and a Flight Data Storage Unit is required for data storage.

These are some of the programs planned for the LTN-72; the point I want to leave with you, is that the LTN-72 is extremely <u>powerful</u> and <u>flexible</u>. If you have an application involving navigation and guidance, the LTN-72 must be considered. Remember, this system has a surprisingly low life cycle cost.

# COMPUTED AIR RELEASE POINT (CARP)

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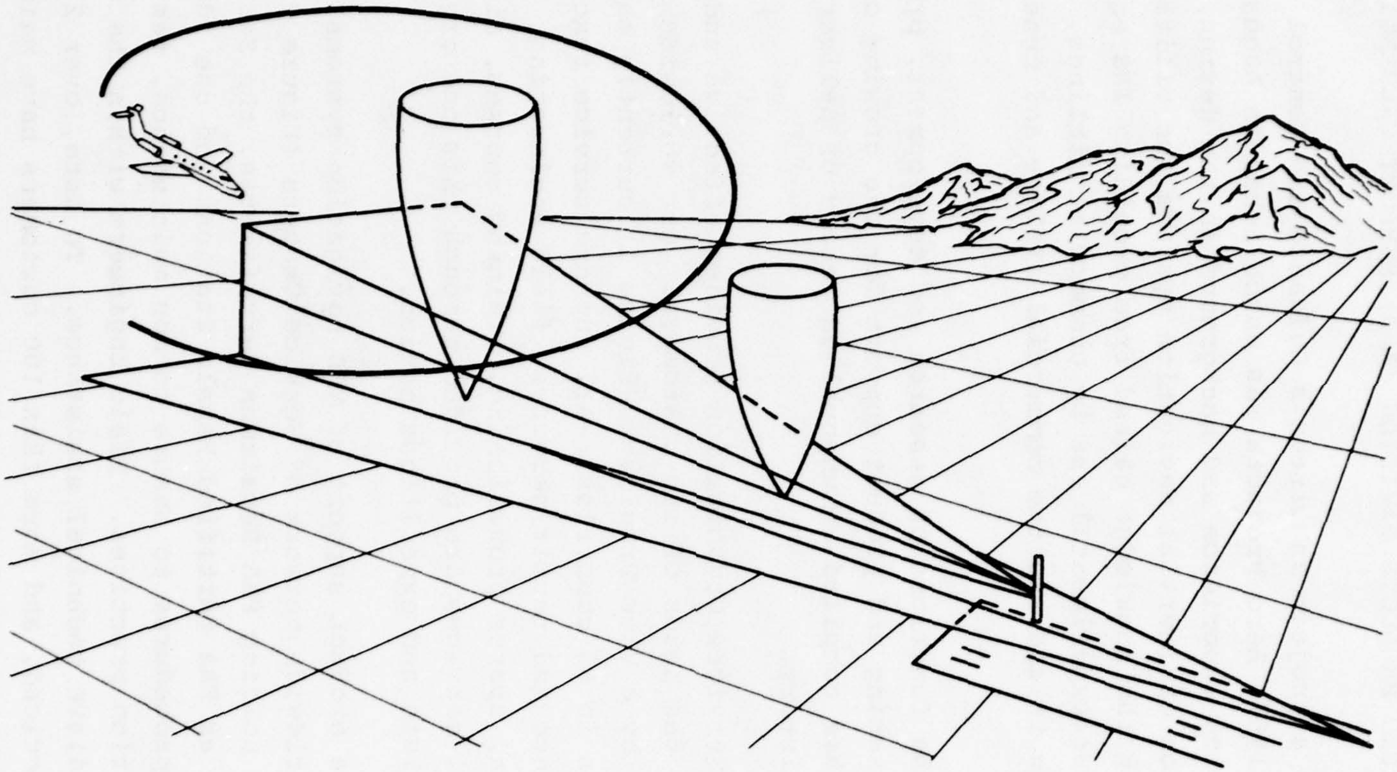
# ACCURACY ENHANCEMENT

808005-8

# FLIGHT INSPECTION



808005-19

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I. LITTON AERO PRODUCTS DIVISION (APD) SUPPORT CREDENTIALS

Beginning as a project in Litton's Guidance and Control Systems Division in 1967, Aero Products was established in August of 1969. With the Litton experience and background in the design, development and production of inertial navigation systems for military aircraft, together with the knowledge gained from providing INS equipment in 1963 for first experimental use by commercial airlines, the young company began to address the commercial airline and general aviation marketplace.

Performing the functions of research and development, product engineering, marketing and product support for the growing commercial market, APD has compiled an unequalled record of delivery in its eight year history.

APD Support Services Organization provides effective and timely service to meet the needs of its customers. Our worldwide support network, headed by a Vice President (Figure 1) currently supports 280 customers in 63 countries. All support service functions, including maintenance and repair services, field engineering, technical documentation, spares provisioning, training courses, airworthiness, and technical services are provided through this one organization to achieve complete and expeditious action.

Comprehensive product support of APD navigation systems is accomplished through a worldwide network of Service Centers (Figure 2). Staffed by personnel holding FAA Repairman Certificates, the Service Centers are operated as FAA Certified Repair Stations and use identical methods and procedures to ensure common maintenance, test, overhaul and modification practices. Field Engineers within the Service Centers provide immediate technical assistance. To date, over 21,000 INU have been serviced, and more than 100 customers have maintenance

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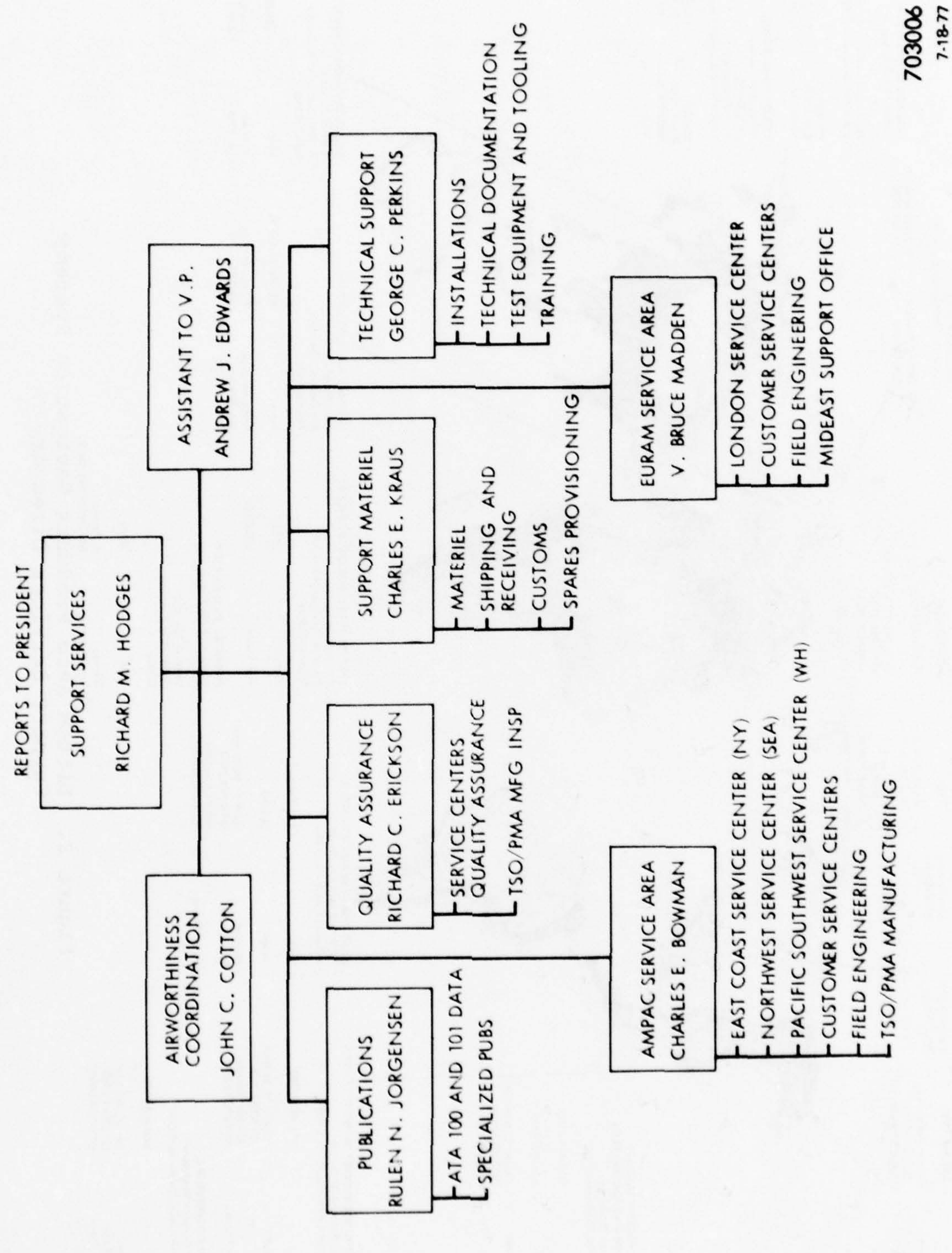


Figure 1. Aero Products Support Services Organization

# TECHNICAL AND MAINTENANCE SERVICES

**NORTHWEST SERVICE CENTER**
Litton Aero Products
331 Andover Park East
Seattle, Washington 98188

| | |
|---|---|
| TWX | 910-444-1640 |
| Representative | Robert Welenofsky |
| Bus. Phone | (206) 243-9111 |
| Home Phone | (206) 237-9020 |

**ATLANTA SUPPORT OFFICE**
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6065 Roswell Road N.E. Suite 301A
Atlanta, Georgia 30328

| | |
|---|---|
| Representative | John Salter |
| Bus. Phone | (404) 252-5915 |

**TORONTO SERVICE CENTER**
Litton Systems, Limited
25 Cityview Drive
Rexdale, Ontario, Canada

| | |
|---|---|
| TWX | 610-492-2110 |
| Representative | Robert Wreford |
| Bus. Phone | |
| Day | (416) 249-1231 Ext. 337 |
| Night | (416) 249-1101 |
| Home Phone | (416) 625-3655 |

**EUROPE, AFRICA, MIDEAST (EURAM) SERVICE AREA HEADQUARTERS**
Litton Aero Products
c/o LPPI
30 Commerce Rd
Brentford, Middlesex, England

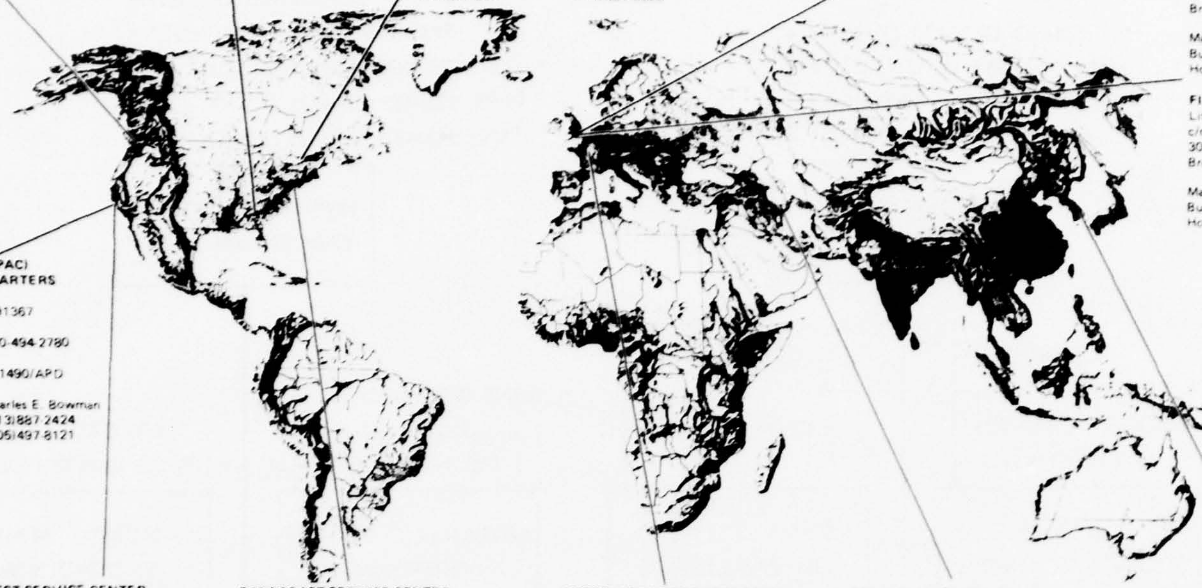
| | |
|---|---|
| General Manager | V. Bruce Madden |
| Bus. Phone | (01) 568-3391 |

**LONDON SERVICE CENTER**
Litton Aero Products
c/o LPPI
30 Commerce Rd
Brentford, Middlesex, England

| | |
|---|---|
| Manager | Robert M. Fleming |
| Bus. Phone | (01) 568-3391 |
| Home Phone | (078481) 2137 |

**FIELD ENGINEERING**
Litton Aero Products
c/o LPPI
30 Commerce Rd
Brentford, Middlesex, England

| | |
|---|---|
| Manager | Kenneth Thor |
| Bus. Phone | (01) 568-3391 |
| Home Phone | (06286) 62371 |



**AMERICAN PACIFIC (AMPAC) SERVICE AREA HEADQUARTERS**
21050 Burbank Boulevard
Woodland Hills, California 91367

| | |
|---|---|
| TWX | 910-494-2780 |
| Telex | 651490/APD |
| General Manager | Charles E. Bowman |
| Bus. Phone | (213) 887-2424 |
| Home Phone | (805) 497-8121 |

**PACIFIC SOUTHWEST SERVICE CENTER**
21050 Burbank Boulevard
Woodland Hills, California 91367

| | |
|---|---|
| TWX | 910-494-2780 |
| Manager | Charles M. Brooker |
| Bus. Phone | (213) 887-2660 (24-hour service) |
| Home Phone | (805) 522-5261 |

**FIELD ENGINEERING**
21050 Burbank Boulevard
Woodland Hills, California 91367

| | |
|---|---|
| TWX | 910-494-2780 |
| Manager | Dan W. Johnson |
| Bus. Phone | (213) 887-2365 |
| Home Phone | (805) 527-9895 |

**EAST COAST SERVICE CENTER**
1770 Walt Whitman Road
Melville, New York 11746

| | |
|---|---|
| TWX | 510-224-6477 |
| Telex | 961355 |
| Manager | Keith H. McConnell |
| Bus. Phone | (516) 293-3133 (24-hour service) |
| Home Phone | (516) 242-5999 |

**LITTON AERO PRODUCTS OFFICE**
Litton Systems, Inc.
9 Avenue Franklin Roosevelt
Paris 8e, France

| | |
|---|---|
| Telex | 29737 |
| Bus. Phone | 225-43-57 |

**PARIS SERVICE CENTER**
Compagnie Air France
DM-L1
Cedex A No. 124
94396 Orly-Aerogare
France

| | |
|---|---|
| Telex | 20666 |
| Manager | R. Taranto |
| Bus. Phone | 535-76-00, Ext. 50-90 |

**MIDEAST SUPPORT OFFICE**
Arya-Sheraton Hotel
Ave Pahlave, Ave Bijan
Tehran, Iran

| | |
|---|---|
| Telex | 212798 SHER IR |
| Representative | Robert D. Toy |
| Bus. Phone | 685174 |

**SEOUL SERVICE CENTER**
Korean Air Lines
Kimpo International Airport
Seoul, Korea

| | |
|---|---|
| Telex | 236235 |
| Manager | Chung Sung Chan |
| Bus. Phone | 8-6131 |

Figure 2. Litton Aero Products Navigation Systems Support Services Directory

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contracts with APD. In addition to the Service Centers' Field Engineers, other Field Engineers are assigned, worldwide, to support installation and maintenance tasks. Since 1969, the number of field engineering hours expended approximates 400,000.

During these past eight years, APD has developed and supported many types of systems. This section briefly describes some of the more important systems which have been accorded support by our Service Organization.

Our first INS certified to ARINC 561 was designated the Litton LTN-51. This navigation system gained a very large number of highly satisfied users among U.S. and foreign Military and other Government and commercial operators of transport aircraft. A second generation ARINC INS, the LTN-72, uses modern dry instrument technology together with a more powerful and flexible digital computer. Another second generation system is our LTN-58 Inertial Sensor System, designed to fulfill the inertial sensor requirements for area navigation to ARINC Characteristic 571 and used with Mark II Class Area Navigation System.

The general aviation LTN-104 Area Navigation System (ANS) is a compact, lightweight, self-contained navigation system used in commercial and business jet aircraft. The LTN-104 ANS may be operated as an Inertial Navigation System (INS) or as an Area Navigation System using automatic DME updating.

Litton APDs DIGIPROX® is a registered design trade name for the ARINC 594 Ground Proximity Warning System. The DIGIPROX® system is a rack-mounted electronic unit which provides audible and visual warnings to alert flight crews of impending inadvertent contact with the ground.

Another sensor system available from APD is the LTN-76 Inertial Sensor system. This system is used as a shipboard attitude and heading reference and a position and velocity sensor.

The LTN-72R is a combination INS and RNAV incorporating all the features of our LTN-72 ARINC 561 INS plus enroute, terminal and approach capability. The economics of the LTN-72R are outstanding because INS and full RNAV are combined into one system.

The APD Airborne OMEGA Navigation Systems (the LTN-201, Mark I built to ARINC Characteristic 580 and the LTN-211, Mark II built to ARINC Characteristic 599) are worldwide, all-weather, airborne navigation systems. These systems utilize the three OMEGA frequencies for automatic synchronization and present position computation to continuously display all guidance parameters necessary for long range great circle navigation.

MORE APD SUPPORT

Support Services Training Program presents various courses of instruction to customer personnel, ranging from system familiarization to overhaul. Each course includes both classroom instruction and laboratory work and allows students to use test equipment in an actual test and repair environment. To date, APD has conducted approximately 1,000 training courses in 70,000 hours for 5,000 students.

Our Publications Organization produces accurate and informative documents in a timely manner. Technical documents available to customers include Operating and Maintenance Instructions, Overhaul Instructions, Service Bulletins and Service Information Letters. Distribution of technical manuals is geared to the user's need with provision of adequate copies to allow the customer to effectively operate and maintain each system. To date, APD Technical Publications has produced and distributed over 400 titles.

During the past eight years, APD has established and supported five Service Centers (Figure 3) and 22 customer-operated Service Centers, seven of which have Third Party Maintenance contracts. APD has

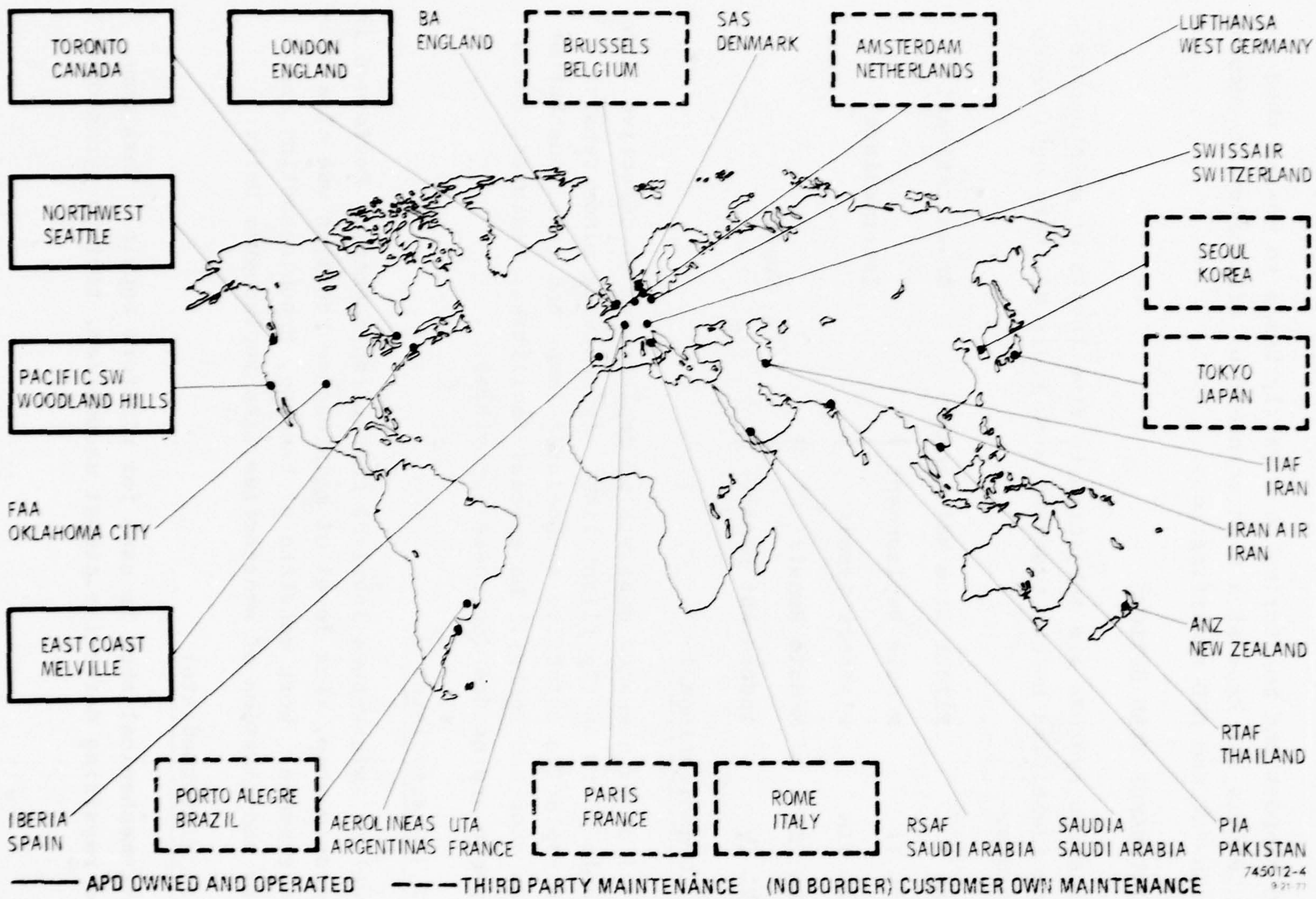


Figure 3. Litton Aero Products Maintenance and Technical Service Centers

provided support and monitoring on a yearly basis to ensure these Service Centers are kept at a high standard of efficiency in accordance with FCC and APD specifications.

## II. MAINTENANCE PLAN OPTIONS

Our navigation systems are subjected to five levels of maintenance. These are identified below, together with their Military equivalent designations.

| | | |
|---|---|---|
| LEVEL I | Flight Line Maintenance | Organizational |
| LEVEL II | Module Replacement | Intermediate |
| LEVEL IIA | Platform Repair | Intermediate |
| LEVEL III | Module Repair | Depot |
| LEVEL IV | Instrument Repair | Depot |

### Level I (Organizational)

This level of maintenance consists of replacement of defective Line Replaceable Units on the flight line. It includes minor repairs (such as replacing defective annunciator lamps and caps, pushbutton lamps and caps and knobs). No special facilities, fixtures, tools or equipment are needed for these activities.

### Level II (Intermediate)

This level of maintenance involves module replacement. Performed in an electronic shop, this level of maintenance requires use of a system test console. Work consists of testing, troubleshooting and repair or modification of a defective Line Replaceable Unit.

### Level IIA (Intermediate)

An electromechanical shop is used for platform repair. Work consists of repairing defective gimbal assemblies, testing gyroscopes

and accelerometers and replacing those found to be defective. This maintenance requires special tools, test fixtures and equipment.

Level III (Depot)

This function deals with comprehensive module testing using electronic shop test fixtures and equipment. Included is the repair of electronic modules by modifying or replacing defective components.

Level IV (Depot)

This procedure involves the repair of defective gyroscopes and accelerometers in semi-clean rooms by specially skilled personnel. This maintenance requires special tools, test stations, seismic isolated test pads and a beryllium working room.

A choice of maintenance performance is open to our customers as shown in the following matrix.

| OPTION | CUSTOMER | | | | LITTON APD | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Levels III & IV (Depot) | | | | Levels III & IV (Depot) | |
| | Level I (Organizational) | Levels II, IIA (Intermediate) | Modules | Instruments | Level I (Organizational) | Levels II, IIA (Intermediate) | Modules | Instruments |
| I | * | | | | - | * | * | * |
| II, IIA | * | * | | | - | - | * | * |
| III | * | * | * | - | - | - | - | * |
| IV | * | * | * | *[1] | - | - | - | - |

[1]Because of extensive capital outlay required to establish this capability, it is recommended that this maintenance be contracted to APD.

III. SERVICES OFFERED TO APD CUSTOMERS

One of the services offered to our customers, whether commercial or Military, is preparation of a document, based on contractual agreements, describing how we will support the applicable system. Known as the Product Support Plan, this document details the services to be provided in a series of separate plans titled:

Technical Data
Training
Logistics (Provisioning)
Technical Service (Field Engineering)
Maintenance

Following is a Product Support Plan prepared for a European airline in 1973 for an LTN-72 Inertial Navigation System. This is typical of the type of document and service provided for our customers. For this application, it has been modified to remove the customer name and reflect Military equivalents of levels of maintenance. Note that Level III (Depot) describes automated test equipment but that manual testers exist for this purpose. References to Litton identify Litton Aero Products Division. The first section in the plan is an Introduction, but this information has already been covered in this paragraph. Therefore the typical plan begins with Section 2.0.

Wherever the plan calls for conformance with commercial specifications such as ATA 100, 101, 200, etc., we have access to the appropriate Military Specifications and incorporate these in the document (according to mutual agreement between APD and customer).

The plan excludes the repair of defective gyros and accelerometers (instruments), which is Level IV (Depot) Maintenance, because of extensive capital outlay required to establish this capability. With this level of maintenance requiring special facilities, tools and major test fixtures, we recommend that this be contracted to APD. Indeed, certain of our airline customers who are flying as many as 100 INS recognize the practicality of assigning instrument maintenance to APD.

Litton AERO PRODUCTS

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IV. LITTON APD MAINTENANCE CONCEPTS

This section address our policies and philosophies on several of our operations.

Turnaround Time (TAT)

APD was first in the industry to provide an average 5-day TAT guarantee for Line Replaceable Units (LRU). We accomplish this by using rotables and operating our Service Centers 24 hours per day and 6 days per week. Actual TAT for fiscal year 1977 was 3.4 days. Our average turnaround for Shop Replaceable Units (SRU) is 15 days and for instruments, 30 days. APD worldwide repair centers have over the years consistently averaged less then the above quoted TAT on inertial navigation systems requiring repair. Also making possible these rapid TAT is our effective maintenance and maintainability based on:

- Experienced, well-trained and dedicated personnel
- Effective BITE fault isolation
- Diagnostic testing which automatically detects and isolates specific faults
- Comprehensive technical repair manuals
- Immediate replacement of defective SRUs with serviceable units to maintain LRU repair flow.

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## Record Keeping

APD field engineers submit bi-weekly activity reports, field repair notices, and unit removal notices to the Field Services Manager for distribution of the information to the Reliability, Quality Assurance and Maintainability Departments. These data are also provided to the Service Center so that a complete repair history of each assembly, by serial number, is applicable at that facility.

With all repaired equipment, the APD Service Center returns a Repair Report that advises the customer or consignee of the details of all repair actions effected on the subject assembly. The established procedure for review and response to reported technical problems is detailed in Section 5.0 of the attached typical Product Support Plan.

## Highlights of Service Center Activities

Units received into the Service Center are subjected to a careful examination and technical review. Should any unit exhibit some unique problem or a bad history (such as: during the last 1,000 unit hours of operation, experienced an MTBR of 200 hours or less), suspected intermittents or non-verified failures, the unit will receive special processing. This sequence, known as Complete Inspection And Repair (CINAR) includes the dismantling of the unit, detailed visual inspection, additional and environmental testing.

Our Service Centers are staffed by employees whose average inertial navigation systems (both military and commercial) experience is 14 years. Many of our personnel have backgrounds dating back to the first production inertial systems. This wealth of experience manifests itself in our history of exceptionally high MTBF and low average turnaround time (3.4 days).

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APD conducts a program wherein our Quality Assurance organization analyzes and measures the repair effectiveness of all APD-operated Service Centers. The purpose of this program is twofold in that it assures a high degree of maintenance performance as well as identifying any individual units exhibiting inadequate performance and possibly requiring special attention. Also, APD has developed a customer Repair Effectiveness program modeled after the one in use at APD Service Centers. This program shows how individual customer-operated Service Centers rank in relation to each other.

APD maintains customer communication on a same-day basis and 24-hour service through our Service Centers and the availability of both home and office telephone numbers of key personnel.

## 2.0 TECHNICAL DATA PLAN

### 2.1 DOCUMENTATION

Litton will provide the following types of manuals covering the overhaul of the airborne units and the operation and service of Litton furnished ground support equipment.

### 2.1.1 Airborne Equipment

The manuals/information provided will be prepared in accordance with ATA Specification 100, Revision 15 and will consist of the following documents:

- Pilot's Guides

  Handbooks detailing pilot's operation of the INS, including predeparture procedures, inflight procedures, and post-flight operations.

- Line Maintenance

  Manuals describing on-aircraft Level I (Organizational) Maintenance procedures.

- Overhaul Instructions

  Manuals covering Levels II, IIA (Intermediate) and III (Depot) Maintenance (overhaul to the circuit card assembly or module level).

- Service Bulletins

  The system user is continually informed of modifications that can be made to improve his equipment. Information is presented as service bulletins with procedures and diagrams for making the necessary changes. By analyzing these bulletins, the user can determine changes advantageous to his own operations before deciding to perform (or contract to have performed) the updating modifications.

- Service Information Letters

  Certain improvements in operating procedures and available updated computer programs are described in these letters and distributed to customers. Data concerning new system configurations and peripheral equipment are also documented here.

2.1.2 Ground Support Equipment

For ground support equipment furnished by Litton, Operation and Service Manuals prepared in accordance with ATA Specification 101 dated 1 May 1967 will be provided.

## 2.2 UPDATE INFORMATION

All service bulletins and information letters, and revisions to all technical manuals supplied will be forwarded to the customer.

## 2.3 PUBLICATIONS

Following is an index of technical documents published to support the operation, maintenance, and overhaul of Litton's LTN-72 airborne equipment.

| MANUAL TITLE/ UNITS-MODULES | CHAPTER/ SECTION SUBJECT NO. | TECHNICAL PUBLICATIONS NUMBER |
|---|---|---|
| Maintenance Level I (Organizational) | | |
| Maintenance Manual | 34-40-01 | TP720 |
| Maintenance Level II (Intermediate) | | |
| Overhaul Manuals | | |
| Inertial Navigation Unit | 34-44-01 | TP721 |
| Control/Display Unit | 34-42-01 | TP722 |
| Mode Selector Unit | 34-44-30 | TP723 |
| Battery Unit | 34-43-90 | TP7000 |
| Maintenance Level IIA (Intermediate) | | |
| Overhaul Manual | | |
| Platform Assembly | 34-44-04 | TP72103 |
| Maintenance Level III (Depot) | | |
| Overhaul Manuals | | |
| ARINC Transmitter | 34-44-29 | TP72122 |
| ARINC Receiver | 34-44-28 | TP72131 |
| Dig/DC Converter | 34-44-02 | TP72101 |
| Computer Type 1 | 34-44-11 | TP72121 |
| Computer Type 2 | 34-44-32 | TP72123 |

| MANUAL TITLE/<br>UNITS-MODULES | CHAPTER/<br>SECTION<br>SUBJECT NO. | TECHNICAL<br>PUBLICATIONS<br>NUMBER |
|---|---|---|
| Computer Type 3 | 34-44-23 | TP72124 |
| Dig/Synchro Electronics<br>Dig/Synchro Transformer | 34-44-03 | TP72102 |
| Attitude Repeater | 34-44-27 | TP72126 |
| Attitude Interface | 34-44-33 | TP72130 |
| Discrete Type 1 | 34-44-25 | TP72129 |
| Platform | 34-44-04 | TP72103 |
| Servo Amplifier | 34-44-05 | TP72104 |
| Power Supply | 34-44-08 | TP72127 |
| A/D Converter Output | 34-44-06 | TP72105 |
| A/D Converter Input | 34-44-07 | TP72106 |
| Monitor | 34-44-15 | TP72113 |
| Mode Card | 34-44-14 | TP72112 |
| Computer Interface 1 | 34-44-24 | TP72125 |
| Computer Interface 2 | 34-44-18 | TP72116 |
| Computer Interface 3 | 34-44-17 | TP72115 |
| Quantizer | 34-44-09 | TP72107 |
| Frequency Control | 34-44-10 | TP72108 |
| Gyro Spin Supply | 34-44-11 | TP72109 |
| Temperature Control | 34-44-12 | TP72110 |
| Filter Phase | 34-44-13 | TP72111 |
| ROM 1 and ROM 2 | 34-44-05 | TP72104 |
| RAM | 34-44-16 | TP72114 |
| Gyro Bias Memory | 34-44-26 | TP72128 |
| Pilot's Guide | None | TP72 |

## 2.4 DISTRIBUTION

### 2.4.1 Airborne Equipment Manuals

Initial distribution of one copy of the Level I (Organizational) maintenance manual per system, 5 copies of the Levels II, IIA (Intermediate), and III (Depot) airborne equipment overhaul manuals and 7 copies of the Pilot's Guide per system will be made to customer. All revisions to these documents will be distributed to customer.

### 2.4.2 Ground Support Equipment Manuals

Operation and Service Manuals, 3 copies per test station, covering the Universal System Test Station will be distributed by Litton directly to customer. All revisions will be provided as required.

2.4.3 Shipping Instructions

All documents distributed by Litton will be shipped to customer per contract instructions at:

Customer's address

# 3.0 TRAINING PLAN

## 3.1 INTRODUCTION

Litton will provide at its Woodland Hills facility training courses in adequate depth to ensure efficient operation and maintenance of Litton's equipment.

Preliminary and detailed courses for cutomer's engineering, training shop and line service personnel will cover:

a) component location

b) maintenance

c) removal/replacement

d) operation

e) inspection/testing

f) modification

g) overhaul (disassembly, fault analysis, repair, reassembly, functional testing) to Level III (Depot)

## 3.2 TRAINING COURSES

### 3.2.1 Standard Courses

Litton will provide the following described courses.

a) Familiarization - 8 hours

This course acquaints technical, administrative, and aircrew personnel with the navigational system description and operation. Contents include basic navigation system fundamentals, navigation system physical description, purpose and description of controls and displays, description of operation modes, system inputs and outputs including interfacing to flight instruments and flight control system. Normal operation during predeparture, departure, enroute, terminal area and post flight are covered with both automatic and manual operation included. A live system mockup is used to allow attendees to observe system demonstration and to perform system operation.

b) Line Maintenance - 24 hours (Level I)(Organizational)

This course acquaints maintenance personnel with basic navigation system concepts, system functional diagrams, system turn on, normal and malfunction indications. Troubleshooting procedures are covered to enable maintenance personnel to isolate malfunctions to a line replaceable unit (LRU). A live system mockup is used to enable attendees to observe fault indications and to reinforce classroom theory.

c) Test Technician - 80 hours (Level II)(Intermediate)

This course covers navigation system fundamentals, functional description of individual line replacement units (LRUs) and system acceptance testing. Troubleshooting procedures are covered to enable maintenance personnel to isolate malfunctions to the module level within the LRUs. Inspection procedures, module removal and replacement and bench adjustments are covered utilizing LRU test equipment and test procedures. Computer testing procedures are covering utilizing computer test equipment.

d) Engineers

The course will provide a detailed functional block diagram analysis of the LTN-72 Inertial Navigation System and System/Aircraft Interface. The course, which is for airline engineering personnel and maintenance planners, is structured to provide the student with a background and insight into the mechanization and testing requirements necessary for system repair to the module level. Proposed ground support equipment will be discussed with applications to module exchange and card repair.

e) Gimbal Overhaul - 120 hours (Level IIA)(Intermediate)

Provides aircraft instrument technicians with the capability to disassemble, repair, and null or calibrate the INS gimbal assembly. Instrument mechanics perform assembly, disassembly procedures, and repair verification by working on actual gimbal assemblies.

Emphasis is placed on coverage of dimensional tolerances and mechanical accuracy necessary to meet overhaul specifications.

f) Electronic Overhaul - 320 hours (Level III)(Depot)

This course covers a functional description of navigation system modules (excluding gimbal assembly) including circuit analyses as required to enable overhaul technicians to troubleshoot to the piece-part level. Module testers are utilized along with comprehensive initial testing and troubleshooting procedures, and computer diagnostic routines. Assembly and disassembly techniques are covered to ensure a fully operable module. Digital techniques and basic system fundamentals are presented to enable maintenance technicians to fully benefit from module functional presentations.

g) Litton Automated Test Set (LATS)

(Level III)(Depot) Operation and Maintenance Training - 320 hours, Part One

Training of customer personnel on the LATS will be carried out at customer's facility concurrent with installation of the equipment. The course comprises both formal classroom lectures and practical training. Instruction covers; function of the system, power supplies, converters, service panel, digital multimeter and interface, and Varian computer programming and hardware. Further coverage includes disc memory, teleprinter and tape reader and punch assemblies. Discussions of the master control unit, distribution units, logic control unit and operations and troubleshooting procedures are part of the course.

(Level III)(Depot) LATS Programming Training - 80 hours, Part Two

Presented in parallel with Part One, this course is intended for programmer personnel and will enable them to generate and implement new test programs. Topics covered include history and applications, definitions and terms, flowcharting test procedures and practical applications.

3.3 TRAINING AIDS

3.3.1 Standard Training Aids

Reproductions of various aids such as projection transparencies and charts used in course presentations, will be made available to customer as specified below.

a) Overhead Projection Transparencies (OPTs)

Litton will provide, as requested, 8-1/2 x 11 inch black and white copies of OPTs and/or illustrations, in a form of acceptable clarity and detail, to permit development of OPTs in customer's format. These training aids will be reproductions of illustrations used by Litton in ATA-100 manuals and/or developed for use in the training courses described in Paragraph 3.2.1.

b) Charts

Charts will be provided as requested. These charts will depict panels, alignment charts, various flight profiles, block diagrams, cutaway views of hardware, and tables and graphs for explanation of navigation fundamentals and basic digital techniques.

c) Slide Tape Training Programs

Slide Tape Training Programs (STTPs) will be provided for basic courses described in Paragraph 3.2.1. These programs will consist of 35mm color slides and magnetic tape with 700 Hz tones available to indicate when slides should be changed. Each STTP is 20 minutes in length.

3.4 STUDY GUIDES - DESCRIPTION

Study guides listed in Figure 3-1 will be provided to support the courses described in Paragraph 3.2.1.

The study guides will include written descriptions and functional diagrams as required to support classroom presentation. A guide will be created to cover specific material necessary for detailed study of course material of each course described in Paragraph 3.2.1. The guide format will prepare the student and will include discussion questions on subtopics to permit the student to measure his study and comprehension progress.

Revisions of the study guides will be on as required basis.

| PUBLICATION NO. | TITLE |
|---|---|
| LTN-72 | |
| TT-72 | System Familiarization |
| SG-72-02 | Line Maintenance |
| SG-72-03 | Test Technician |
| SG-72-04 | Platform Assembly |
| SG-72-05 | Electronic Overhaul |
| SG-72-05A Vol I | INU Computer Overhaul |
| SG-72-05A Vol II | INU Computer Practical Exercises |
| SG-72-05B Vol I | INU Digital Electronics Overhaul |
| SG-72-05B Vol II | INU Digital Electronics Practical Exercises |
| SG-72-05C Vol I | INU Analog Electronics Overhaul |
| SG-72-05C Vol II | INU Analog Electronics Practical Exercises |

Figure 3-1. Study Guides

# 4.0 LOGISTICS PLAN

## 4.1 INITIAL PROVISIONING DATA

Provisioning data will be provided by Litton for provisioning of spares and ground support equipment for all items considered to be rotable or recoverable. The data will be provided in accordance with provisioning requirements of ATA Specification 200, Revision 9. If these documents, in final form, are not available in time to provide adequate coverage for initial operation, preliminary versions suitable for use by customer in initial provisioning activities will be provided.

## 4.2 CHANGES TO PROVISIONING DATA

Changes to provisioning data will be furnished as required.

## 4.3 INITIAL PROVISIONING SPARES

Litton will deliver all initial provisioning spares as mutually agreed to by customer and Litton.

# 5.0 TECHNICAL SERVICES

## 5.1 CUSTOMER SERVICES

During the support period, Litton will provide customer with three facets of customer service.

### 5.1.1 European Administration

EUROPE, AFRICA, MIDEAST (EURAM)
SERVICE AREA HEADQUARTERS
Litton Aero Products
c/o LPPI
30 Commerce Rd.
Brentford, Middlesex, England

Bus. Phone: (01) 568-3391

will supply coordination and administrative services in connection with Litton equipment, technical support by way of "in house" consideration of field problems and consultation. The Service Center is responsible for field engineering emergency assistance when required.

### 5.1.2 Worldwide Service

Litton's United States facilities/personnel are available in support of European activities, if required. In addition, this ensures coverage for customer's aircraft in the United States and overall responsibility for Litton worldwide service. Technical personnel will be available to assist in any unusual or peculiar situations that may arise which would require special study or analysis.

### 5.1.3 In-Service Problems

The Field Service Department has an established procedure for the review and response to technical problems reported from the field by field engineers, Litton customers, or the maintenance facilities. Reported problems are investigated and answered by the Support Engineering group.

5.2 FIELD SERVICES

5.2.1 Resident Field Engineer Service

Litton will assign a field engineer to customer to provide technical assistance in flight line maintenance, further training of aircrews and maintenance personnel, interpretation of technical data and on-site liaison. In addition, the field engineer will assist in training personnel in the use of Litton's unique test equipment. The length of the assignment will be determined by the need for assistance.

5.2.2 Non-Resident Field Engineer Service

Litton will provide, as required, field engineering assistance on special assignments to meet the needs of the customer.

5.3 MODIFICATION AND REPAIR INFORMATION AND ASSISTANCE

When modifications become necessary to Litton equipment which are Litton's responsibility (as defined by contract), the following services will be provided promptly at no charge:

a) Modification and repair data in accordance with ATA Specification 100 Service Bulletin format.

b) Modification kits as required.

c) Rotable assemblies to expedite the rapid completion of field modifications.

d) Inspection, maintenance, overhaul, and modification services performed on an as-needed basis throughout the program.

e) Any special tools and/or fixtures for modification.

f) A Service Bulletin Index periodically.

g) A repair capability for the complete Litton equipment will be maintained by Litton to provide immediate response to repair customer equipment.

Where changes are not Litton's responsibility, the above services will be provided at reasonable charge.

## 6.0 MAINTENANCE PLAN

### 6.1 MAINTENANCE SERVICES

#### 6.1.1 Assistance to Customer

Litton will assist the customer in the planning, training and setting up of its own maintenance services through Level III (Depot) maintenance for the INS. The assistance will be accomplished as noted in Sections 2.0, 3.0, 4.0, 5.0 and this section, as well as by special consultations deemed necessary by the customer and Litton to achieve an effective maintenance service.

#### 6.1.2 Modification and Maintenance Service

Complete repair and retrofit services will be available to the customer as required throughout the life of the program. Litton is prepared to provide complete warranty repair services commencing with the delivery of the first navigation equipment. During the life of the program, Litton will evaluate all phases of the modification and repair services. Revisions to these services will be made as required to maintain proper facilities and services to fulfill warranty and purchased repair commitments. All Litton facilities will be manned by personnel holding FAA Repair Certificates and operated as FAA Certified Repair Stations, with identical methods and procedures to ensure common maintenance, overhaul and modification practices. Litton will satisfy warranty repair claims by either the performance of repair, or the reimbursement to the customer for materials and services necessary to make such repairs.

#### 6.1.3 Spares Support

As long as Litton's equipment is installed in the customer's aircraft, Litton will, at its facilities, maintain an adequate stock of units and spare parts to meet cutomer's needs for unit replacement, repair and overhaul. Delivery lead time will not exceed 30 days for stock items; and 90 days for items not normally stocked. Also, Litton will maintain a stock of or supply to customer, spare parts of types and kinds not manufactured by Litton but used in its equipment.

Customer has the right to procure Litton's units and spare parts, not only direct from Litton, but from any other source. To preclude possible system degradation resulting from the use of these parts, customer will coordinate such procurements with Litton.

Litton will provide a spare parts stock in Europe. The content level of such stock will be based on the statistical distribution of failure of the applicable spare parts.

## 6.2 SERVICE CENTER PLANNING

Figure 6-1 summarizes maintenance levels and the following paragraphs delineate the basic requirements/capabilities needed by the customer to plan and establish a Level II, IIA (Intermediate) and III (Depot) maintenance service.

The recommendations are based on 1 to 30 active LTN-72 systems for Levels II and IIA (Intermediate), and 1-60 systems for Level III (Depot) are are discussed in a time sequence to achieve Service Center readiness.

| | ORGANIZATIONAL | INTERMEDIATE | | DEPOT |
|---|---|---|---|---|
| | LEVEL I MAINTENANCE | LEVEL II MAINTENANCE | LEVEL IIA MAINTENANCE | LEVEL III MAINTENANCE |
| 1. Definition | Replacement of defective line replacement units on the flight line end replacing defective annunciator lamps and caps, front panels, pushbutton lamps and caps, and knobs. No special facilities, fixtures, tools or equipment are needed for these activities. | Repairing defective line replaceable units by testing and troubleshooting, and replacing defective shop replaceable units. Level II maintenance is performed in an electronic shop and requires special test fixtures and equipment. | Repairing defective gimbal assemblies by fault isolation and replacing defective gyros and/or accelerometers. Level IIA maintenance is performed in an electromechanical shop and requires special tools, test fixtures, and equipment. | Repairing defective electronic modules by testing and troubleshooting, and replacing defective components. Level III Maintenance is performed in an electronic shop and requires special test fixtures and equipment. |
| 2. Accomplished by | Customer | Litton/Customer | Litton/Customer | Litton/Customer |
| 3. Requirements | | | | |
| a. Test Equipment | None required | System Test Station<br><br>Pedestal Assembly | System Test Station (used for Level II Maintenance)<br>Pedestal Assembly | Litton Automated Test Set (LATS)<br>Quantizer Tester<br>Power Supply Tester |
| b. Tools | None required | Card extenders (22) | Platform Tooling | Electronic Shop Tools (Card Extenders (12)) |
| c. Facilities | None required | Standard electronics shop - on ground floor isolated from excessive vibration | Clean work station | Standard Electronics Shop |
| d. Spare | Mode Select Unit<br>Inertial Navigation Unit | Electronic modules (rotables) | Gyros and accelerometers (consumables) | Components (consumables) |
| e. Training | Line Maintenance Course - 24 Hours | Test Technician - 80 Hours | Overhaul Technician - Electromechanical - 120 Hours | Overhaul Technician - 320 Hours |
| f. Documentation | Line Maintenance Manual | ATA-100 Overhaul Manuals | ATA-100 Manuals | ATA-100 Overhaul Manuals |

Figure 6-1. Levels of Maintenance Summarized

6.2.1 Technical Publications

The types of publications required for the various levels of maintenance associated with cutomer's LTN-72 Service Center are outlined in Figure 6-2.

| MAINTENANCE LEVEL | PUBLICATION DESCRIPTION | QTY PER SET |
|---|---|---|
| I (Organizational) | Maintenance | 1 |
| II (Intermediate) | Overhaul | 4 |
| IIA (Intermediate) | Overhaul | 1 |
| III (Depot) | Overhaul | 30 |

Figure 6-2. Technical Publications

The plan for Litton-provided documents is detailed in Section 2.0.

6.2.2 Labor Skills

Figure 6-3 defines the required labor skills, and establishes the maintenance level associated therewith.

In order for the customer to have trained personnel possessing the required skills when the first aircraft is available, the personnel must be selected early allowing for sufficient training time. Litton's training plan is detailed in Section 3.0 and is arranged to meet the schedule and skill needs of the customer.

| SKILL DESCRIPTION | MAINTENANCE LEVEL |
|---|---|
| ELECTRONIC TECHNICIAL<br>Must know electrical and electronic fundamentals including solid state devices as applicable to circuitry in inertial navigation equipment. Must know basic theory of computer operation of system components such as flip-flop circuits, gating circuits, memory devices, gyros, accelerometers, synchros and resolvers. | II, IIA & III (Intermediate and Depot) |
| ELECTROMECHANICAL REPAIRMAN<br>Must have sufficient mechanical ability and dexterity to perform assembly and disassembly of gimbal units. Remove and replace gyroscopes, accelerometers, gimbal segments and other component parts of gimbal assemblies that have failed. Perform retrofits on gimbal assemblies working from Engineering Change Orders, Engineering Rework Authorizations, retrofit bulletins, schematics or verbal instructions. Must be able to use applicable tools and soldering equipment as necessary to perform the described tasks. | IIA (Intermediate) |
| ELECTRONIC ASSEMBLY REPAIRMAN<br>Must be able to complete the following tasks. Repair electronic assemblies, such as printed circuits and terminal boards, harnesses, chassis, plugs and connectors, by soldering, pinning, routing, grouping, tying wires, and removing failed components. Remove from electronic assemblies failed microelectronic devices such as integrated circuit assemblies and replace with serviceable components. Apply touch-up epoxy and conformal coating to repaired units. Perform assembly and/or retrofit of electronic assemblies working from Engineering Change Orders, Engineering Rework Authorizations, retrofit bulletins, schematics, wire lists or verbal instructions. Perform continuity check of printed and handwired circuitry. | III (Depot) |
| REPAIR STATION INSPECTOR<br>Must understand procedures, repairs, modifications and test for incoming, preliminary, hidden damage, in-process and final inspection. Ensure that electronic and electromechanical assemblies conform to blueprints, schematics, retrofit instructions, and workmanship and repair standards. Perform random surveillance inspections during functional testing of electronic modules and systems. | II, IIA & III (Intermediate and Depot) |

Figure 6-3. Labor Skills

### 6.2.3 Training

The standard courses available are shown in Figure 6-4 and are detailed in Section 3.0. On-the-job training is provided by Litton on-site field engineers. During the initial operation of the Customer Service Center, Litton field engineer will assist the maintenance personnel in the areas of general operation, procedure review, troubleshooting and future planning. Litton's basic field services plan is detailed in Section 5.0.

| COURSE DESCRIPTION | HOURS | MAINTENANCE LEVEL |
|---|---|---|
| Line Maintenance | 24 | I |
| Test Technician | 80 | II |
| Engineers | 32 | II |
| Platform Overhaul | 120 | IIA |
| Electronic Overhaul | 320 | III |

Figure 6-4. Training Courses

### 6.2.4 Provisioning

Customer must have in stock certain types and quantities of spares. These spares are categorized into the Maintenance Levels I, II, IIA (Intermediate), and III (Depot) defined in Figure 6-1.

Litton will provide provisioning data in accordance with ATA Specification 200 Revision 9, and general assistance in the procurement of spares. Litton's plan for provisioning is detailed in Section 4.0.

### 6.2.5 Facility Planning

a) Facility Requirements

The facility requirements for a maintenance center covering Maintenance Levels II, IIA (Intermediate), and III (Depot) are detailed in Figure 6-5.

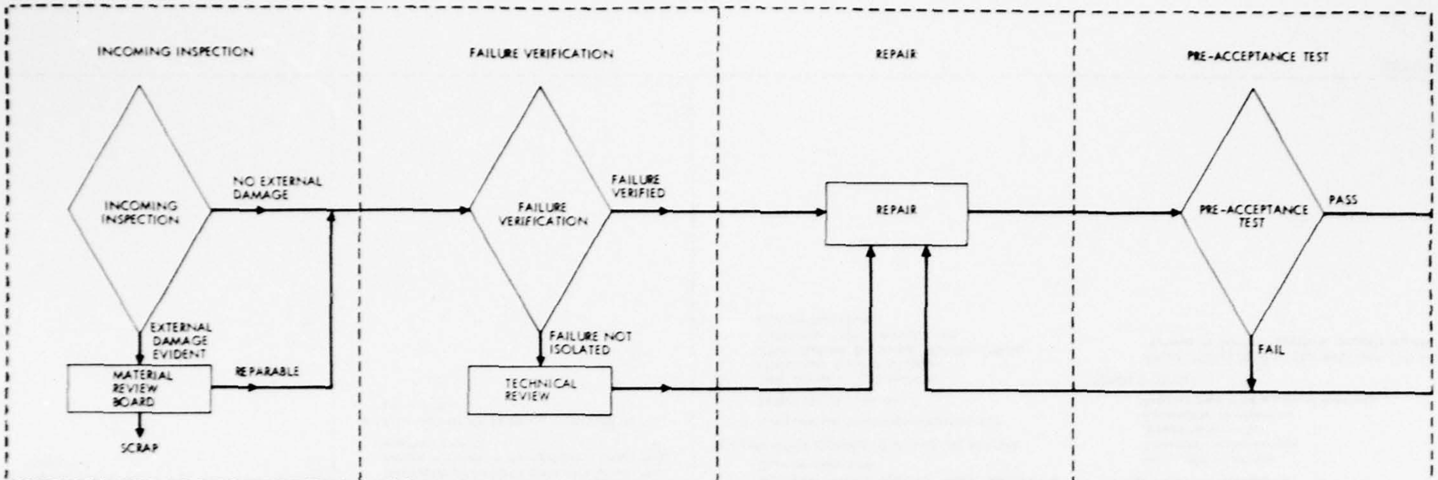
b) Service Center Flow and Procedures

Figures 6-6 and 6-7 provide a recommended hardware flow and document control sequence.

| FACILITY | LEVELS II & IIA (INTERMEDIATE) | LEVEL III (DEPOT) | TOTAL II, IIA & III |
|---|---|---|---|
| SPACE | | | |
| Shop | 200-250 sq ft | 600 sq ft | 800-850 sq ft |
| Storage | 100 sq ft | 300 sq ft | 400 sq ft |
| POWER: | | | |
| 115V/ 400 Hz | 1 Receptacle (30 amp) | 2 Receptacles (1) (20 amp each) | 1 Receptacle (30 amp) 2 Receptacle (20 amp each) |
| 115V/ 60 Hz | 4 Receptacles (20 amp each) | 3 Receptacles (20 amp each) 1 Receptacle (40 amp) | 7 Receptacles (20 amp each) 1 Receptacle (40 amp) |
| or | | | |
| 230V/ 50 Hz | 4 Receptacles (10 amp each) | 3 Receptacles (10 amp each) 1 Receptacle (20 amp) | 7 Receptacles (10 amp each) 1 Receptacle (20 amp) |
| FURNITURE: | Desks, Chairs, Benches, File Cabinets, Storage Cabinets | | |

[1] 400 Hz power at each receptacle should be unaffected by, and independent of, the load at any other 400 Hz receptacle to the extent of ±3 relative voltage variation. Waveform variation should be minimal.

Figure 6-5. Facility Requirements




NO EXTERNAL DAMAGE

- Initiate Failure Report in accordance with operating instruction 4.2 (APD Form 18). Obtain adequate failure data
- Initiate Repair Report (APD Form 28) in accordance with operating instruction 4.3
- Fill out and attach green "REPARABLE" Tag (APD Form 116)

EXTERNAL DAMAGE EVIDENT

- Photograph damage, obtain three prints (one for Repair Center, and attach two to Repair Report and send to Litton Aero Products Division, Woodland Hills, California 91367, attention of Warranty Administration)
- Notify Customer
- Submit Unit to Material Review Board
- Process Damage Claim

OBSOLESCENCE AND SCRAP

All parts and assemblies designated as "scrap" will be sent to Litton Aero Products, 21050 Burbank Blvd Woodland Hills, California 91367, Attention: Quality Assurance Manager. Copy 5 of the Failure Report will be retained by the originator

- Perform detailed technical review of unit history and reported malfunction. Those exhibiting any of the following conditions will receive special processing:

  Bad History

  Suspected Intermittents

  Non-verified Failures

- Initiate "History Data Log Addendum Sheets" (APD Form 92) (all significant occurrences throughout entire repair/test cycle must be recorded on this form)
- Environmental testing is used only as a trouble-shooting technique and is not a requirement of the Repair Center

- Install replacement module(s)
- Repair chassis
- Verify subassembly failure in slave line replaceable unit. (Failed subassemblies will be subjected to the repair flow as follows:)

  Initiate Failure Report (APD Form 18)

  Complete REPARABLE tag (APD Form 116)

  Route items through following operations:

  Inspection (damage check, connector check, green tag)
  Test (troubleshoot)
  Repair
  Test (applicable acceptance test procedure)
  Inspection (area of rework, sockets, general damage) and attach a "SERVICEABLE" yellow tag

- Control of module substitution is important and every effort is required to maintain the inventory in a consistent status

- Test in accordance with applicable Maintenance Test Procedure

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Figure 6-6. Service Center Flow (Page 1 of 2)

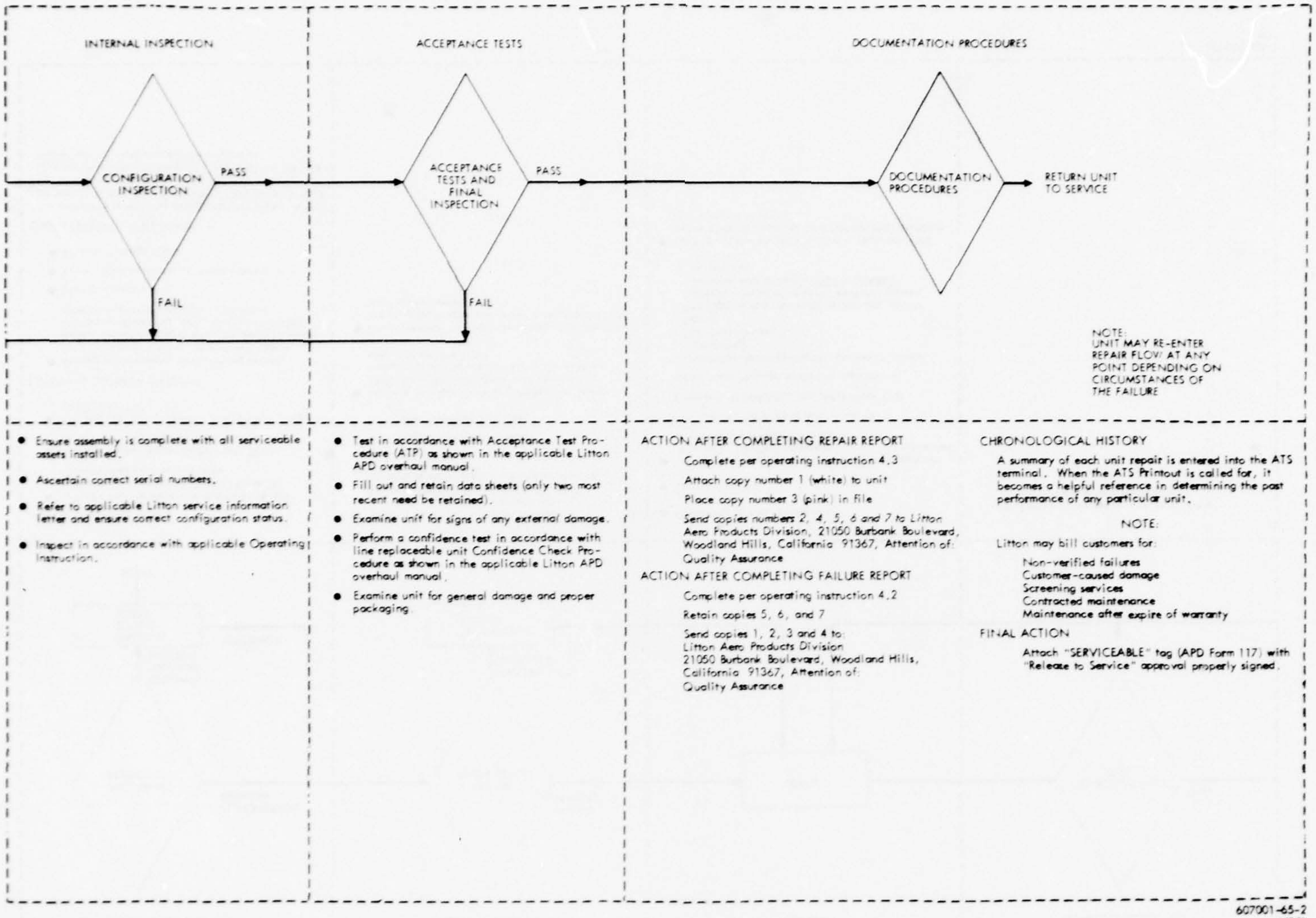


Figure 6-6. Service Center Flow (Page 2 of 2)

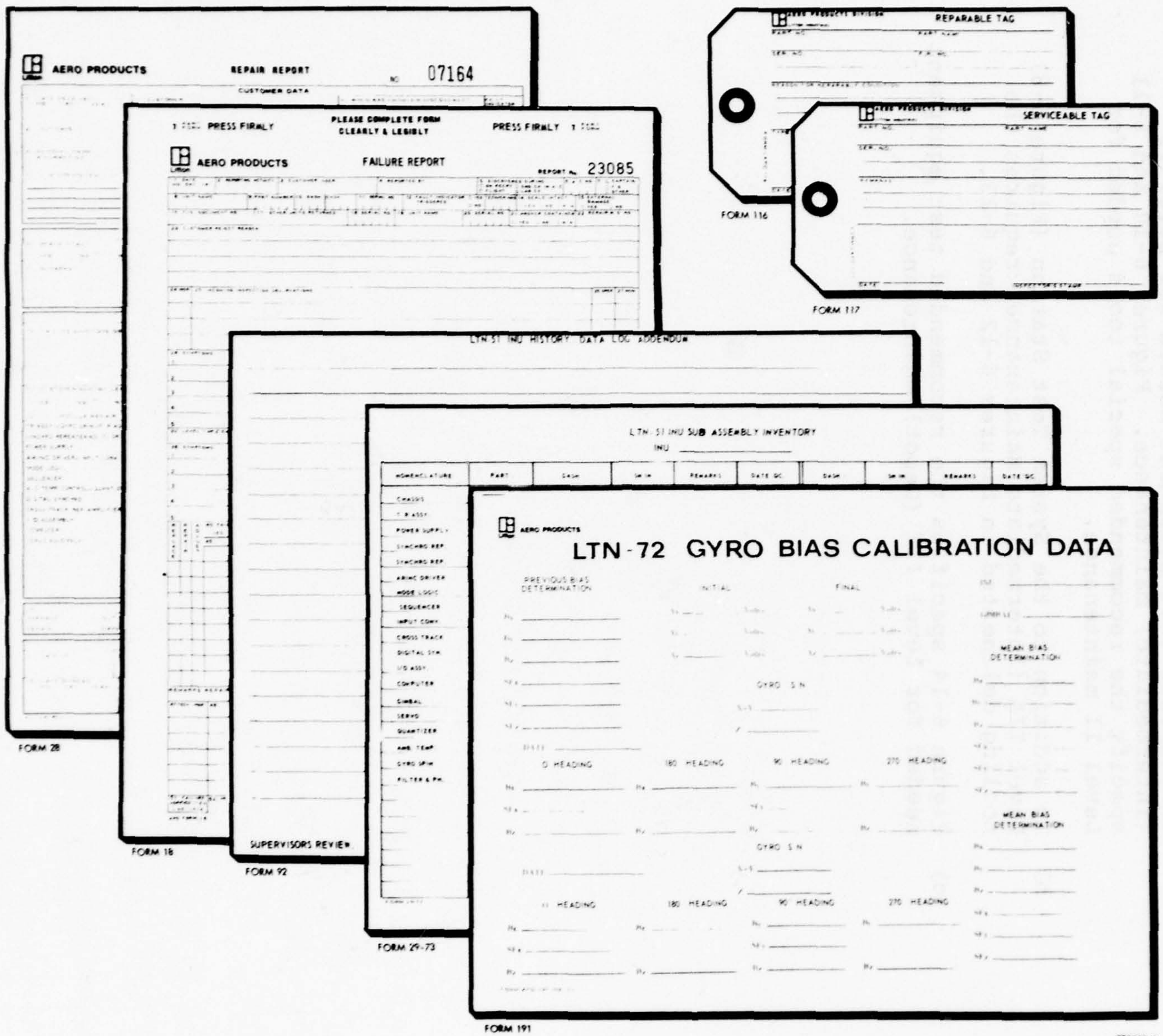


Figure 6-7. Service Center Controlling Documents

6.2.6 Test Equipment and Special Tools

a) Figures 6-8 and 6-9 specify the recommended maintenance test equipment needed for Level II (Intermediate) maintenance. Figures 6-10 and 6-11 specify the recommended special tools needed for Level II maintenance.

b) In addition to the System Test Station (Figure 6-8) Level IIA (Intermediate Maintenance) requires the tooling delineated in Figures 6-12 and 6-13.

c) Figure 6-14 specifies the recommended test equipment needed for Level III (Depot) maintenance.

| NOMENCLATURE | PART NUMBER | QTY REQ'D |
|---|---|---|
| SYSTEM TEST STATION | 07227-1* or 07227-3* | 1 |
| Pedestal Assembly | 662895-04 | 1 |
| Three-System Burn-In Station** | 451099-01 | 1 |
| Manual Computer Control | 250350-1 | 1 |
| Tape Reader | 240500-1 | 1 |
| Extender, Modules: | | |
| Quantizer Assembly | 453787-01 | 1 |
| Gyro Spin | 453791-01 | 1 |
| Temperature Control | 453794-01 | 1 |
| Frequency Control | 453797-01 | 1 |
| Control/Display Unit | 453801-01 | 1 |
| Computer Type 1 | 452204-01 | 1 |
| Computer Type 2 | 452204-02 | 1 |
| Computer Type 3 | 452204-03 | 1 |
| Computer Interface No. 1 | 452204-04 | 1 |
| Computer Interface No. 2 | 452204-05 | 1 |
| Computer Interface No. 3 | 452204-06 | 1 |
| Gyro Bias Memory | 452204-07 | 1 |
| Dig/Sync Transformer | 452204-10 | 1 |
| Dig/Sync Electronics | 452204-11 | 1 |
| ARINC Receiver | 452204-12 | 1 |
| ARINC Transmitter | 452204-13 | 1 |
| Discrete Type 1 | 452204-14 | 1 |
| Attitude Interface | 452204-18 | 1 |
| A/D Converter | 452204-19 | 1 |
| A/D Multiplexer | 452204-20 | 1 |
| Mode Logic | 452204-21 | 1 |
| Monitor INS | 452204-22 | 1 |
| ROM 1 INS, ROM 2 INS | 452204-23 | 1 |
| RAM Memory, 256 x 12/24 | 452204-24 | 1 |
| Digital-to-DC | 452204-26 | 1 |

*Recommended commercial test equipment, as listed in Figure 6-9, is included in these configurations. If the customer chooses to provide the recommended commercial test equipment, System Test Station Part Numbers 07227-2 or 07227-4 will be required. Part Numbers 07227-3, -4 add full capability for LTN-51 usage.

**Optional

Figure 6-8. Recommended Level II Test Equipment

| NOMENCLATURE | PART OR MODEL NUMBER |
|---|---|
| Litton-Designed Panels | |
| ARINC Simulator | 07253 |
| Power Control | 07249 |
| Display/Mode Select | 07245 |
| Avionics/Interface | 07239 |
| Test No. 1 (LTN-58, LTN-72) | 07229 |
| Test No. 2 (LTN-51) | 07234 (07227-3) |
| Commercial Test Equipment | |
| Simulated Battery Supply (28 volts dc) | Hewlett-Packard 6268B-026* |
| Chart Recorder (with 2 preamps, type 8801A) | Hewlett-Packard 7702B** |
| Oscilloscope (with preamp type 1801A and time base type 1821A) | Hewlett-Packard 180AR |
| Digital Multimeter | Fluke 8110A |
| Synchro/Resolver Bridge | Gerstch DSRB5CD4R |
| Phase Angle Voltmeter (with plug-in SF-1) | Gerstch PAV-4 BR |
| Angle Position Indicator | North Atlantic API 8025 |
| Stop Watch | Hueur 542704 Monte Carlo |

*-026 is 115v. For 220v eliminate dash number.

**-11 has speed reduction 60:1 (60 Hz).
-8, -12 have speed reduction 60:1 (50 Hz).

Figure 6-9. Console Complement

| NOMENCLATURE | PART NUMBER |
|---|---|
| Assembly Tool | TP5710 |
| Assembly Tool | TP5712 |
| Assembly Tool | TP5713 |
| Assembly Tool | TP5714 |
| Assembly Tool | TP5709 |
| Assembly Tool | TP5719 |
| Removal Tool | TP5747 |
| Removal Tool | TP5753 |

Figure 6-10. Level II (Intermediate) Special Tools Required

| NOMENCLATURE | PART NUMBER | MANUFACTURER |
|---|---|---|
| Punch | SA2360 | Borg |
| Crimp | SA2047 | Borg |
| Crimp Tool | 614430 | Buchannan |

Figure 6-11. Level II (Intermediate) Recommended Commercial Tools

| NOMENCLATURE | PART NUMBER |
|---|---|
| Stable Element Handling Fixture | T8711 |
| Stable Element Holding Fixture | T8741 |
| Holding Stand | T8737 |
| Null Fixture (Outer Roll and Gimbal) | T8705 |
| Wrench | T8702 |
| Wrench | T8704 |
| Null Fixture (Azimuth and Inner Roll) | T8714 |
| Wrench | T8701 |
| Wrench | T8703 |
| Tool Insertion | T8708 |
| Null Fixture (Pitch) | T8715 |
| Break Out Board | T8731 |

Figure 6-12. Level IIA (Intermediate) Tooling Required

| NOMENCLATURE | PART NUMBER | MANUFACTURER |
|---|---|---|
| PAV | PAV 4BR | Gerstch |
| PAV Plug-In | SF1-400 Hz | Gerstch |
| Audio Oscillator | HP 202C | Hewlett Packard |

Figure 6-13. Level IIA (Intermediate) Recommended Platform Tooling

| NOMENCLATURE | PART NUMBER | QTY |
|---|---|---|
| Litton Automated Test Set (LATS) | 06902 (Top Assembly)<br>07400 (Main Frame) | 1 |
| LTN-72 INS Adapters | | |
| No. 5 (digital) | 06691-1 | 16 |
| No. 6 (assorted) | 06692-1 | 3 |
| No. 7 (analog) | 06693-1 | 12 |
| No. 8 (assorted) | 06694-1 | 9 |
| Atlas Program | TBS | |
| Power Supply Tester | T14180 | 1 |
| Quantizer Tester | T14145 | 1 |

Figure 6-14. Level III (Depot) Recommended Test Equipment
Litton Automated Test Set (LATS)

INTERNATIONAL LOGISTICS

CHAIRMEN

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BRIGADIER GENERAL J. T. EDWARDS

HQ AFLC, Wright Patterson AFB OH

It is certainly an honor for me to be with you to kick off the international symposium portion of your program. It's a very exciting topic. I've been in my current position as Commander's Assistant for International Logistics for about four months and I can tell you that there are many policies and many procedures that are lacking in this business that need to be developed and we are working very hard at that task. I spoke with the Commander last night following his presentation here yesterday and he mentioned to me that he really didn't have time to get into all the topics that he wanted to and he asked that I take up where he left off. That's going to be a pretty tall order to follow, I assure you.

But the security assistance program, I think, is a very complex, very important program. But it's also controversial. If you read the newspapers in the United States, as most of you do, you find various opinions about the security assistance program, whether it's good for the United States, whether it's good for the globe, for the world, for that matter.

You can find the range spreading all the way from a very critical position to one that favors it as a stabilized factor and a way to achieve world peace.

I am going to touch on that a little bit this afternoon, then I want to get a little more specific in terms of what we do at AFLC and what we think we can do in the future.

Most of my comments, although I am representing the Air Force, and I am representing the Logistics Command, are really

Department of Defense positions. Things that are happening throughout all of the services, because the one thing we are trying to do in the International Logistics Program is to present a common face to our customer countries so that they do not have to develop an understanding of the Air Force, the Army, and the Navy and our various ways of doing business. Most of my comments apply across the spectrum of military services and countries that might be interested in doing business with these services.

First of all, I'd like to begin with a few facts just for background. Many of you may be familiar with these, but I want to use them to emphasize the latest statements that have been made by the President concerning our policy with respect to the security assistance program.

When I speak of security assistance program, I am talking about grant aid and foreign military sales. They are both embraced, but you should appreciate that the grant aid program is on the decline. As a matter of fact, the Congress has said there will be no further grant aid in terms of military assistance after the conclusion of the fiscal year '77 just passed. In other words, beginning with the first of October, there will only be grant aid for military assistance as specifically designated by the Congress. In the '78 bill, they only will designate eight countries and the total grant will probably only be about 250 million dollars, so we are talking about a very small program. So security assistance is almost synonomous with foreign military sales.

About half the international trade in military arms and services over the last five years has been from the United States. So when you hear the President talk in terms of applying discipline and constraint to arms trade, he must certainly be referring to

the United States, since we in fact supply over half the military arms around the world.

Last year we did more than nine billion dollars worth of business with 68 countries. A four-fold increase in the last five years so it's a very, very dynamic, and growing program.

At the same time while we took orders for nine billion dollars last year, we have on hand 36 billion dollars worth of orders that are signed and have not yet been delivered. So even if we were to begin tapering off the program, we would be still delivering goods for another five or ten years at about the same rate that we are delivering in the current year, about the nine to ten billion dollar level. More than 60 percent of this business is with the Middle East. Specifically the three countries of Israel, Iran and Saudi Arabia constitute the bulk of our program.

About a third of our trade last fiscal year was with NATO, Japan, Australia and New Zealand. About 40 percent of that trade was for weapons and ammunition. The remainder, of course, being training, services and supplies. So while it would appear that we are -- it goes beyond appearance -- we are in fact very much involved in the arms business throughout the world, it's useful to look at the kinds of arms that we are talking about and then measure one country against another in terms of what kinds of equipment.

For example, the Soviet Union in transferring military arms is in fact the leader in terms of quantities of tanks, artillery, surface-to-air missiles and supersonic combat aircraft. So not all of our military arms shipments with the idea of

stabilizing defense in a reasonable area, as opposed to giving a country a particular capability that will upset that balance.

For over a quarter of a century, arms transfers have been a very useful instrument in U.S. foreign policy and I want to give you a few examples because it's important that you understand that our security assistance program is an element of our foreign policy. Where it does not enhance the national security of the United States, where it does not promote reasonable stability, an arms agreement will not be entered into no matter what the economic advantages that would have accrued to the United States were to do so.

So there is no economic justification for security assistance programs and if you get nothing more out of my presentation today than that, I will be satisfied. Now it's not to say that there are not economic benefits that accrue from the program, there are in fact. They benefit both the customer country and the United States in terms of reducing the unit cost and in terms of broadening the logistics base. But those are secondary objectives, the benefits, and are never a determinant in whether a program will be sold or not.

So we have used the security assistance program to strengthen our collective defense arrangement and to encourage allies to assume a stronger self defense role as in NATO, and I think that example is very clear. We also maintain regional balances as in the Middle East. I think you can see the importance of the security assistance program there where the free world's vital energy resources lie.

We secure base and operating rights for U.S. forces with the security assistance program, as in Spain, Turkey and

the Phillipines. We strive to limit Soviet influence and to enhance our own friendships in specific regions and with particular governments as in Africa.

We offset or we compensate for the withdrawal of U.S. forces with the security assistance program as in Korea.

Those are some specific ways in which the security assistance program constitutes an element of our foreign policy and these particular objectives can be generalized further as examples of legitimate objectives of our security assistance program.

In more general terms, it benefits us by assisting our allies, friends and international organizations to strengthen their capabilities, to maintain internal security, to defend against external threats and to contribute to regional defense. It also encourages close ties and enhances inner-operability in NATO. The Congress specifically passed a bill recently to direct a more two-way kind of participation in NATO to enhance this inner-operability and standardization.

We are interested in standardizing doctrine, training and equipment, not only in NATO, but throughout the free world. We think that this program benefits both the buyer and the seller in terms of standardizing equipment such that we can operate together when contingency requires that we do so.

It also develops cooperation. It also develops more allies. It brings us closer together with nations that have the same kinds of objectives that we have in terms of stabilizing arms trade and promoting peace throughout the world.

So this cooperation extends not just between the military organizations but out into industry and to the political arena as well.

These are some of the real political advantages and military advantages, if you will. It also, as I mentioned, provides a broader logistics base to draw upon -- I'll touch on that a little further -- and hopefully reduces the unit cost of equipment by allowing us to buy in scale.

There has developed, however, a growing concern that however laudable the ends, the high export of arms carries with it serious liabilities such as the United States as an arms merchant. You've heard in the last presidential election, the President say he did not understand how we could hope to achieve the leadership role in developing world peace and yet also be the world's largest arms exporter. So there is serious concern about the United States as an arms merchant.

There's also serious concern that it constitutes a loss of technology for the United States. And that by exporting our most sophisticated kinds of equipment, that through reverse engineering we are in fact also exporting our technology. And we will lose the advantage that we currently have with the Soviet Union.

Also people have mentioned that this kind of merchanting in arms exacerbates the overall arms race. That the more countries receive arms, the more their neighbors need arms, the more they need sophisticated arms, so that it continues to exacerbate trade and the arms race and thereby weakens really the opportunities for peace.

You've also heard it said that it weakens our own support base. That we have been asked to support other countries in such

a timely fashion that we don't have the procurement lead time to go out and make new procurements and therefore we have to draw down our own forces in order to constitute the sale.

It also adds work, adds work without the additional man-power so that we are also draining our work force in terms of supporting our own forces.

Well, the new arms transfer policy described by the President in mid-May represents an effort to recognize and deal with these kinds of contradictions. I won't debate these with you in terms of whether in fact we are loosing technology we are exacerbating the arms race, but needless to say there are enough people in the United States that share these feelings that the President feels it necessary to deal with them.

So clearly the prime factor in the decision process remains that it must be shown that the transfer of arms contributes to our national security interests.

After this test, a number of new controls were specified by the President. He has directed and we will, of course, do the following things: We will reduce the dollar volume of new commitments to sell weapons and weapon-related items in 1978. No firm dollar objective has been given although he did say that in terms of '76 dollars, '78 sales would not exceed '77 sales. But he is also very much in the review personally now and will review along with the Congress all sales that exceed 25 million dollars.

And in this review, it will be not just in terms of matching dollar amounts, but it will be a measure of contribution that

particular sale will make to world defense, and the United States' national security interests.

Secondly, the President has said we will not be the first to introduce advance weapons into a region that creates a new combat capability and we've seen recent examples of that in terms of Latin America, principally, is the example that comes to mind. We will not sell weapons that are not in the inventory of our own armed forces and you've seen that when the President declined to sell the F-18 to Iran. We will not develop advanced weapons solely for export, which if we had this policy some years back, it would certainly have been a blow to the F-5 program, but it will be the policy for the future.

We will curtail the production of U.S. weapons and components by foreign governments, which says that mutual agreements to produce weapon systems in other countries will come under closer scrutiny and in fact will be more difficult to achieve.

We will discourage the re-export of U.S. equipment to third countries. Now, the current policy today will allow a country when it wishes to upgrade its defense forces, to sell to a neighboring country or to some other country that's interested in their inventory, those equipments that were procured from the United States, provided that the Congress gives that approval and the Congress is given 30 days to consider that. The President's policy would indicate that the Congress will probably not approve many third-country requests for transfer of equipment.

Lastly, and the one that hits industry the hardest, is an intention on the President's part to strengthen regulations governing business and government sales abroad. Now, he's really indicated that for sales that exceed 25 million dollars, will go through the Foreign Military Sales Program except for the NATO countries.

I don't know exactly what he has in mind at the moment in terms of strengthening regulations governing business and sales abroad, since they are already very tight, but I think we can expect to see something in the next four or five months.

These will not be easy tasks for us because our preeminence and our predominance as an exporter of arms comes because both our government and our industry have together established a reputation as a reliable supplier and supporter of the best equipment and service available, number one. And secondly, because we have a very strong congruance of interest and objectives with those countries that are interested in these arms. Since the ultimate test of whether or not a sale will be made is the contribution that that particular sale makes to the national security interest and to the stability of the region to which the arms will go, we can see that on a case-by-case basis, not all of these conditions may necessarily hold. Because the governments that buy our weapons have defense requirements which they view as urgent and legitimate as our own. And genuine defense requirements, I think, will continue to be recognized in spite of the constraints the President announced in May, but our policy, I think, can be said, will be one that seeks to restrain world wide traffic in arms. So discipline and restraint, I think are the keynotes in our future negotiations.

We've had some four or five months now since the President's policy announcement in May to see how they will work, and in fact we have negotiated with 18 countries separate sales for some 480 million dollars worth of business, so the arms trade is certainly not coming to an end.

Decision-making in this arms transfer business is a very deliberate process and it's done at the highest levels of the government. The State Department is of course the first part of the executive branch that becomes involved with security assistance programs. They must worry about the relationships of one country to another if this arms agreement goes through. The Defense Department, of course, it's very clear what our role is, our concern is the military capabilities that will be added and what impact it will have on our own forces. Labor, Commerce and Treasury are concerned about jobs, the economy and the balance of payment and these concerns are in fact expressed in the decision to make a sale or not, or to reject them.

Plus the questions of arms control, human rights and compromise of technology are all dealt with in the executive branch.

This is kind of the overview of the current climate in the international logistics community. You could hardly fail to be acquainted with them because you can find in the newspaper every day some editorial, some comment on our current policies.

This brings me down to AFLC and our role here at Wright-Patterson in the security assistance program. Because of all this interest and because of the growth, with '74 actually being

the peak year in the United States in terms of not only sales agreement, but also deliveries. I think in '74 we delivered about nine billion dollars worth of arms overseas and there were orders given in the free world of a little over 20 billion. With this kind of tremendous growth in our foreign military sales program, General Rogers formed my office to advise him in how the program should be pursued from a logistics point of view and to develop policy and procedures that the Command would follow in providing the follow-up support to the weapon systems that were being sold throughout the world.

We centralized case management at Wright-Patterson and a new organization called the Air Force Acquisition Logistics Division. While their principal charter is to transition from the development phase to the support phase and to bring lessons learned from weapons that are currently being supported into the research and development process, they were also given a secondary role in security assistance.

In that, they would centralize all the individuals performing case management for the 63 countries we currently deal with. So at Wright-Patterson, my office in the Headquarters is involved with the policy and procedures, the Acquisition Logistics Division is involved with case management and case negotiations and the five air logistics centers or depots throughout the United States involved in the actual procurement, packing, shipping of the items that have been negotiated for sale. So that's the relationship within the Command. The depots are still very active in our program and are in fact, the worker bees, if you will. The management comes in the Acquisition Logistics Division and the oversee and the policies comes in my office.

Now there are three programs that we are in the middle of that I thought you might be interested to hear just a little bit about. We have a program in Iran to develop a logistics command, if you will, very much like our own. There are large numbers of weapon systems that are going into the country that exceed the capabilities to manually provide for their logistic support. So they have asked, we've developed a statement of work, and a contract has been awarded to Lockheed for 108 million dollars over the next six years to develop in Iran a logistics command. It will be responsible for not only the organization and the manning of this particular command, but also for all the software, hardware programs and facilities throughout the country of Iran.

In Saudi Arabia, we have a program to develop three bases and in the military construction of these three bases is involved not only the runways and equipment for the aircraft and the maintenance, but also for base housing and the associated housing facilities that go with that.

This all stems principally from the F-5 program and in terms of not only developing the facilities but also the training and maintenance capability associated with those aircraft.

In Spain, a very similar kind of contract will soon be awarded if we don't in fact develop for the Spaniards with our organic capability a requirements and computation system for investment and expense items very much like our own system.

We find that in working with the various customer countries that the biggest stumbling block to negotiating for logistic support is the lack of a requirements computation system. We take in our own Air Force our flying program and our past history

over a two-year moving average and we compute our requirements for the two years ahead of us. We also take for the expense items, the bit parts and pieces, and we take the demand history over the last two years, the moving average, and we found over time that this gives us about the optimum support for the dollars that one could hope for. We find that this kind of a system doesn't exist in many of the countries that we do business with and there's a great difficulty in trying to predict and forecast their requirements so that we can in fact incorporate them with our own requirements in the procurement process. So we are working now on a requirements computation system that could be exported to the various countries that are interested in our cooperative logistics program.

Our cooperative logistics program allows a customer country to use the United States Air Force logistics system. Now the Congress has said that you will not buy in anticipation of a foreign military sale, so we can't buy spare parts in anticipation of need of a particular country and without a requirements computation system, the country has great difficulty in predicting into the future, so we have a dichotomy.

And the way we have solved that, or the way we are solving that is through a cooperative logistics program that allows a customer country to come in, sit down with our negotiators, who in turn will, based upon our understanding of the flying program and what they attempt to do with a particular weapon system, develop for him a follow-on support package for about 17 months. We ask him then to fund for the front end of that for five months, putting

the other one year of that definition on order. This then allows us to buy, using his money in anticipation of his requirement; but incorporate that with our own procurement process. This has worked out very well for us in the past. We are still working on improvements to this cooperative logistics procedure, but it does allow him to requisition for parts against the Air Force supply system as though he were another Air Force base and the software and the computers and the item managers at the depots will respond to these requisitions in some fashion as they respond for our own Air Force bases.

Now, that's not to say we don't have problems. As a matter of fact, we do. The biggest problem we have is the fact we are undermanned for this program. This program has taken off at such a great rate that we were found wanting in terms of manpower, in terms of policy, in terms of procedure. So we are a little bit behind the power curve in dealing with this tremendous growth.

We find the lead times on all the items have been practically cut in half. The Department of State enters agreements to support a particular country and the country has that expectation, yet those expectations and those agreements do not in every case recognize the lead time, particularly in the avionics and electronic components. So there is a great deal of pressure applied upon us to make that difference up.

As I mentioned, very few procedures are available and little guidance. Plus, we get very little feedback. Once we have completed a case and the requisitions begin to flow, we really don't know until that country is in deep trouble and the problem has been elevated from government to government, State Department to

State Department. We don't get the opportunity to work with the bases and the customer countries like we do with our own Air Force bases at the sergeant and lieutenant level, so most of our problems come in from the top down.

However, when we look at our management indicators, we find that, at least so far as the United States Air Force is concerned, we are operating better today than we have in the past. So I, for one, have to stand up and say that our security assistance program is not degrading our own readiness and our own military capability.

Well, what are we doing about this tremendous growth program and these problems? We are getting organized, as I mentioned to you earlier, with the Acquisition Logistics Division and with the formation of my own office.

We are taking a corporate view of the security assistance programs. The Air Staff in the Pentagon has formed a group very much like the Air Staff Board, if you are familiar with that organization, chartered to do nothing further than to look at security assistance programs, look at new requests to see how they will in fact work in and fit with Air Force programs. We are developing training courses and you will hear in just a moment one of the newest programs the DISAM, Defense Institute for Security Assistance Management, and the Deputy Director is here today to talk to you about that. I think this will certainly go a long ways towards correcting the deficiency we have with undertrained people.

We are developing guidance, Department of Defense instructions improving our communications and we are taking a business approach

to our contracts. I understand you've talked a little bit about procurement practices and the difficulty with implementing reliability improvement warranties, not only with the Air Force, but it also creates quite a problem in procurement, I think, for security assistance programs.

I have, incidentally, accredited to my office liaison officers from 13 different countries and they are for me the greatest source of feedback in terms of how well the program is going and what kind of improvements and corrections we can make and I certainly follow their recommendations in practically every case.

But I have a very optimistic outlook. I think that we are stabilizing, I think the security assistance program is leveling off. I think it will level off for the Department of Defense at about 10 billion dollars a year. We are establishing routines. We are automating. We are developing software programs and we are getting greater cooperation. And I think the cooperation will extend itself into depots overseas.

I've not mentioned much about the F-16 program, although it is a very major program within the international community and I was mentioning just at lunch today I think it's very likely that we will have a depot overseas that will be not a part of the U.S. industry, but will be a part of the industry of one or more of the European countries that will perform work not only on the European F-16, but all the United States Air Force's F-16s in Europe.

So I see growing from this program much greater cooperation among military services and among industry.

We will never be free of problems. As we have with our own commands, we will attempt to allocate dissatisfactions equally which is, of course, the job of the logistician resource manager as resources will always be limited.

Thank you very much for your kind attention.

COLONEL VAN RAFALGHEIM

BELGIUM

Colonel, gentleman. First of all I thank the Colonel to ask you to stay with me and try to understand what I have to tell. My mother tongue, as a matter of fact, is not English or North American -- I'm not even from the South.

The sponsors of this -- I have to make you sorry of my papers I wrote this morning in my room here. I arrived yesterday night at 11:00 o'clock and that doggone F-16 is so busy I couldn't even put my ideas on a piece of paper and I think I might need that today. When I walked in this morning and I saw all you people I said I'd better prepare something instead of talking from the top of my hat.

Anyhow, the sponsors of this Joint Services Data Exchange for Inertial Systems asked me to brief you on the planned logistics maintenance program for the F-16. And more particular towards the F-16 consortium countries.

There is one thing to avoid any possible misunderstandings for an international business, you have to be careful sometimes. I would like to point out that many of the considerations and ideas or comments I express here concerning international logistic policies reflects my personal opinion and are not necessarily shared by my Air Force or my other lords and masters.

To start out that brief presentation, I would like to give you a very short overview of what really the F-16 consortium coproduction program is.

As you know, or you don't know, it is a five-nation partnership between the U.S., Denmark, the Netherlands, Norway

and Belgium. And these five nations entered a co-production venture in 1975 which means that the five together will be building the F-16 aircraft, manufacture their 100 engines, manufacture weapon system accessories and other parts in five different nations. One assembly like on the American continent and four others in the European countries.

It's very important to realize that when you see what complication problems and coordination problems can be if you have to coordinate and plan a program with a pond of three or four thousand miles in between.

Two end-assembly lines in Europe and one in the United States will be delivering aircraft to the consortium countries. Other European industries will manufacture and deliver aircraft components, accessories, LRUs, SRUs, for those that are familiar with those terms -- I hope you are -- Line Replaceable Units and Shop Replaceable Units -- for the different systems and subsystems. Inertial systems business comes in Norway, is a good example here as a second tier subcontractor from Singer-Kearfott in inertial system area.

The co-production of the weapon system resulted in an important industrial arrangement and transfer of technology. Also we offer a great advantage to provide a more efficient NATO incorporability to standardization, which in turn will result in other economic benefits to all parties involved and I think in this case, General Edwards might choose the term economic benefits, since it is for the good sake of our common security.

This very standardization effort to eliminate the large diversity of equipment and materials used in the NATO forces and diversity has always resulted in an increased maintenance and

overall logistic support costs.

In order to enable now our defense system to operate in a completely coordinated manner, we also have the task to develop a coordinated, integrated international logistic support system, which should not only tend to standardize procedures and maintenance concepts, but should act to an increased industrial stability and yet a united community through the active but coordinated industrial participation in the support areas as well.

I think it is quite important, especially for the European NATO partners in this program.

The F-16 logistics support task is a tremendous one and a challenging one at the same time. Particularly when one realizes that we try to deliver the schedule, which in turn leads to a simultaneous worldwide base activation in a compact time frame never seen before. Just think of the number and complexity of the logistics aspects which need to be covered and coordinated between different nations.

Just to cite some examples in the support equipment area. The selection, development, the procurement. In other areas, like the spare parts, provision procedures, procurement, spare parts identification, repair parts identification, facilities, transportation problems, data collection problems, development and refinement of maintenance concepts as common as possible, development of cost effective repair capabilities, which takes into account the economical considerations of every individual country involved, particularly in the depot level area.

I repeat it is a tremendous task. But going and already in very many areas well established on a firm, solid base and in the

true spirit of partnership.

Some examples of the on-going effort in the F-16 logistics area. For organizational intermediate level, I think we have about 400 items there which have been identified already, about 100 of them are F-16 particular and peculiar items and the other 300 are items which are government furnished equipment or already existing on at least U.S. inventory.

Apparently we have reached the 85 percent point for identification of support equipment for organizational and intermediate level. The depot level area is not yet finished and I think we are there about 30 to 40 percent.

In the government furnished airborne equipment area, I think we have already have 1200 items there with spares identified at approximately 30,000.

Technical publications 150, with 15,000, maybe 16,000 pages.

All that has to be worked out and combined and coordinated between the five nations and not only coordinated into different concepts, into different ways of looking at solutions, but also taking into account very often with very great language problems and barriers.

With regard to the F-16 maintenance concept, that's one of the biggest of the logistic support area. We can say that fortunately the four co-producing F-16 European partners to the U.S. had already a maintenance concept which is quite comparable to the United States Air Force concept. That does not necessarily mean that it is structured and organized in the same way. But it is also being worked out.

The effort in the maintenance data collection area is a very good example here. New concepts even to the U.S., well, rather

new, anyhow, have become part of the F-16 logistic support system. Concepts such as the reliability improvement warranty.

If the organization on the intermediate levels of maintenance are rather or relatively easy to deal with for each nation individually, the problems related to the depot level concept are far more complex and difficult to handle. Especially in an international environment.

One might still think for reasons such as self support operation, independent of foreign sources, shorter part line times with a lesser volume of assets and thus lower costs, more investments, that an entire depot capability is required for every single country involved. I think, and I'm not the only one, we should realize that for high complex and high technology equipment this vision might no longer be a very valid one.

Initial required investment and exploration costs are tremendously high and become prohibitive and the whole operation might become not even cost effective, but a loss.

Setting up a depot, I don't have to tell you it's a very expensive venture. You have to look at facility requirements, tools, special test equipment, materials, and spare parts at the depot level, that you have to put up consumables, engineering manpower and so on and quality assurance and all that taken into account the number of repairable generations throughout the life of the aircraft or the system.

For smaller countries, and coproducing countries, this might be a very, very serious problem for the follow-on logistics area, but also in the industrial and economics area and the soughtfor increased industrial stability might be lost if there

is no overall involvement of these countries.

The solution to this problem I feel must be sought in the conclusion of international agreements in the area of depot repair capability by trying to establish a solid corporation basis in this area as well. This means that there where the creation of depot level repair capability is no cost effective for small countries, they should enter into agreements whereby they accept to develop a repair capability on behalf of several other countries. The larger countries which are part of such an alliance or consortium should also participate be it to maintain a competitive environment and to avoid monopolization in other areas.

The way we approached it and with the European F-104 consortium in 1960, '63 time frame is a good example, and I think has shown that if we want to make it work, we can make it work, and I was very pleased to hear today that it is the firm intention of the United States to go that way, for the F-16, go that route and have maybe a European depot in support of even the U.S. aircraft, and the European aircraft as well.

I would like to conclude this small presentation to address anyhow a meeting for INUs, to illustrate what the possibilities would be for as in the area of the INU. For a period of time, we will have no real problems, no real depot capability, no real depot need, since there we have that reliability improvement warranty concept. It is very limited in time, though, for the United States for instance. They need to have a depot capability right down from 1981 already and for us it will be the Belgium Air Force, at least it will be about the same problem since the number of aircraft falling under that reliability

improvement warranty is limited and the time span is also limited.

From this point in time, the U.S. anyhow, can use its own capability already existing here, I presume, and which can easily be extended to the new INS and further they are also able to use the contractor capabilities.

For the European partners however, are in a different spot. Contractor depot level maintenance we can go for an arrangement with the United States Air Force on cooperative logistic cases or can go direct to the U.S. contractors. Individual countries might want to look into again owning depot repair capabilities. Or, as I said, reach international agreement between and among the Europeans or with the U.S. and come up with a depot, for instance, with a subcontractor who has already to a certain extent a certain capability but which doesn't mean that he has got a depot level repair capability. These are different possibilities. But, are they cost effective, that's another issue.

Cost effective it would be for the Belgians, I think, in any case, to come back and say, okay, we go for U.S. depot level repair capability.

The other nations might or might not agree, but there is also another problem related to that: Are they valid in the political, economical considerations, are they acceptable? And I said, the coproduction venture was accepted because they wanted some more industrial stability and aeronautical industries and they have not only the idea, they are confident, and I think they are right, to follow on to maintain these weapon systems or that weapon system in Europe that they will also have their

share of the pie.

The second solution is a European subcontractor could adapt its own coproduction capability into a depot repair capability for four or five nations, or part of it, as a second source, for instance. That might be a valid approach. And maybe cost effective. And as part of an eventual European agreement become acceptable from political and economical and other standpoints.

The third solution would be one country or every single country would go for its own depot maintenance and that is not only applicable to the INS, it is applicable to an awful lot of other accessories and components of a weapon system, be it the F-16 or another one. It's just outlandish. Investment -- initial investment -- like in the area of the INS, could not be borne by smaller countries. I can hardly see with my budget trying to find 50 million dollars in there to buy test equipment required for INS testing and I'm not talking about the facilities required. It is not justified to think about sophisticated equipment like laser balancing installations for gyros, the necessary computers and surely not for the small numbers of repairable generations.

The comparison between the three mentioned possibilities might also become suggestive for a fourth possibility. And it means that where we could have a normal ONI level at the bases which is normal and understood, you might have a limited depot level in-country, which is in between the full depot repair capability, which might be in the U.S. or in Europe or in both places, with or without contractor participation.

Maybe we could have a limited depot capability could be envisioned as a repair center where only electrical cards or SRUs could be tested on automatic test equipment, where the repair could be done, integrated circuit replacement and things like that and we are now trying to go into platform gyro or accelerometer repair.

If the repair is beyond staff capability, send it on to full depot capability somewhere. It is clear that a more thorough study, however, will be required to determine if this solution would be cost effective or not and as you can see, we have still quite a ways to go to get to a maintenance concept or policy for problems related to the depot level. But I'm pretty confident that we are working hard and going to get there in a very timely manner. Thank you very much.

COLONEL RON SHACKELTON, USA

DISAM, Wright Patterson AFB, OH

COLONEL SHACKELTON: Since Colonel Huff brought it up, being from Newark, New Jersey, you know why I went infantry. I was pretty well qualified from my boyhood days. He mentioned wiggling in your chairs, and most of you have either instructed or been speakers somewhere along the line and they kind of point out that if you have any control over it, try not to schedule your presentation right after lunch for obvious reasons, and secondly, avoid following eloquent speakers, in this case General Edwards and Colonel Huff, and third, try to stick to your allotted time. I have no control over the first two, but the third I do and I will try and stay very brief. As a matter of fact, I have prepared a complete briefing that we have from the DISAM and I think with your indulgence I'll kind of stray from that and make some remarks and talk to a few slides that I brought and hopefully no one is in a location that you won't be able to see the screen.

Defense Institute of Security Assistance Management -- we're proud of our little emblem there primarily because we started in January, it was approved in July, and after approval we knew that we were in fact in business. There it is. I must also mention that we haven't come up with a color scheme yet and that takes another meeting of the Policy Guidance Council, so it may be another year before we can get the colors approved, but we are on our way.

I had a brief introduction as to why the Institute was formed, but I think General Edwards very adequately covered rationale and the need of a Security Institute which provides education at the management level of the security assistance business. As he pointed out, it's big business. It's a business that's here to stay. It's a tool that impacts very heavily upon our foreign policy. Because of all this, it's a complex business. Complex for many reasons because its fibers run through the economy of our country, through the defense industry and so on.

Because of that, it was determined that we may have to look at our educational process to try and standardize the services in many of their approaches and methods of security assistance functions and perhaps find better ways of simplifying some procedures and regulations and the like.

So as a result of this, the Defense Institute of Security Assistance Management became a reality. It was organized and we are established at Wright Patterson Air Force Base with our first full course of instruction commencing October 3rd.

As you'll see later, we go throughout this year on various pursuits to satisfy DoD requirements.

Along with the educational process, I think you are well aware, even though most of you are in the technical aspect of maintenance and this type, engineering aspects of security assistance or production, I think that all of you understand full well the dynamics and the complexities of security assistance and therefore the problems associated with trying to develop an educational program that meets all the needs of all the people that are in this business; from specialists and technicians like yourself and

engineers and maintenance, to those in procurement, to those in training, to those providing logistic support and transportation, the full gamut. And those are the people that we are chartered to provide some type of education and training for.

Our mission is pretty well self-explanatory. Conduct courses of study, which I'll elaborate on in greater detail in a moment. Conduct research, primarily research aimed at improving the managerial or the administration of security assistance programs and also provide consultation. Consultation is really training and education for those people who are already educated and trained and working in security assistance who can come to us for some assistance on the latest developments in security assistance.

In our education role, our primary responsibility, as I pointed out, is to conduct a course of study to prepare personnel for assignments in security assistance and MAG or other overseas positions. That's important, as I'll point out a little later. Students represent the three military services, both military and civilian, and additionally as you'll see later, we also have courses on instruction for our foreign purchaser or our foreign student.

Our curriculum is designed and serves a common purpose for security assistance from a DoD viewpoint, although we do cover the service-unique requirements of all the services in special seminars.

Along with this mission, we found that there was a need to have a repository, a central location that would habitually keep current and maintain the security assistance legislation directives

and so on from which others can draw upon in their security assistance efforts.

Our research requirements are also geared not only in the educational process but also to assist other educational institutes such as the other service schools in preparing their curriculum and each of them have some bit of security assistance education. Also as I pointed out, assist those from a consulting role that are already in security assistance positions.

Along this line, we start with what we call our SAM C course, which is the core course. This is geared primarily to those people that will be in security assistance positions or are already in security assistance positions. It is structured to give the students a basic, comprehensive overview of security assistance concepts, policies and procedures. In the 15 class days, we cannot expect to make experts of individuals in all aspects of security assistance. But we do provide each and every student with a working knowledge of all requirements and procedures including hands-on training, computer simulation, case studies and whatever it might be to insure that we are providing the management level of training that is required for them to perform their jobs properly.

The course is logistics oriented but we include foreign policy, legislation, industry viewpoint, State Department requirements, DoD procedures for carrying out those State Department decisions in both foreign military sales, even in military assistance program, the grant aid program. Even though they are being phased out, we still have people working very

heavily in those areas. To bring the students through all the procedures and requirements for processing security assistance cases.

As pointed out here, the course is designed for government employees -- military and civilian -- I want to make that very clear. It's not completely a military educational facility. In the grades as you see, E-7 to O-5, GS-7 to GS-14, although we have had O-6s and GS-15s in the two courses that we have already conducted. We find that particularly for someone newly assigned at that high position or high rank, that they are finding it extremely beneficial in getting done what needs to be done so that they can assume their position rapidly.

The course is also designed primarily for the CONUS student in this regard. However, it is required and I'll get into the SAM O that anyone going overseas must attend the core course before we get into the O course. This overseas course is eight days, a follow-on, a trailer, if you will, of the SAM C course upon which we now hit very heavily on some of the peculiarities of his position overseas in a MAG or even perhaps an attache, or in a mission or mil group, to where he now must advise the services or the country team or the ambassador or whoever it might be in the security assistance area. So we cover that very heavily, the JSOP, the Joint Strategic Objectives Plan, the (?) and some of those documents as well as giving him orientation on the area in which he is going to by bringing in experts in the field of that particular country. We talk about protection from terrorism, how to get along with the country team, channels of

routing security assistance cases and cultural aspects, communications aspects, this type thing, we try to produce during the SAM O follow-up. Again designed for the same level grade structure as the core course, however, we do make exceptions.

The SAM F course is primarily for the purchase countries, the foreign countries, their people who will be working in security assistance. It's a nine class day curriculum, streamlined and designed and instructed primarily from the purchaser's viewpoint, what he needs to do. It's primarily our core course, but we cull out many of the things that he's really not concerned with, like the channels for pricing that goes through our financial chains. We talk about legislation. We make him aware of why our government is doing things the way they are doing it. So he has a better understanding of our security assistance program so that he can do his job better in filling out the letter of offer, but also, very important, he knows why the Americans in the MAG or whereever in his country, why they are required to do certain things that perhaps make their job a little bit easier. The foreign officers and civilians, primarily the management level grades who are in security assistance positions.

Now, it's interesting to note at this point and I'm sure you're all well aware -- perhaps you're not -- that a recent reduction in all the MAGs overseas -- a great reduction. A lot of these people work in security assistance. It has created in those MAGs and missions and ODCs, Office of Defense Cooperation, which is primarily the same as a MAG to rely more heavily now on their nationals working for the U.S. in security assistance.

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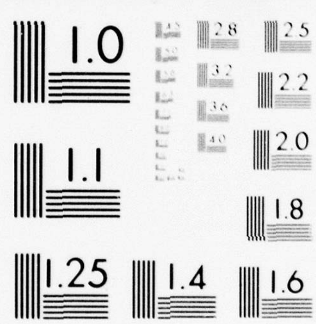



MICROCOPY RESOLUTION TEST CHART

And as a result of this, something we completely overlooked in developing our forces, some of the ODC's and MAG's are coming in and saying,"Hey, can you train some of these third country nationals for us who are going to be working for us." So we're down to the field now. We are querying them about what the desires and impact will be and basically what it is they want instructed and perhaps next year at this time we'll have a SAM FN or whatever course we may have.

So talking about dynamics in security assistance how one decision in this case, reducing the MAGs but another requirement out. We are continually striving to meet the needs of the government security assistance programs.

Our SAM S course is primarily a combination of the SAM C course and the SAM O course, a synthesis of these. However, it's designed primarily for the senior officials, the senior officer, O-6, O-7 level, who is going overseas to be Chief of the Mission or Chief of the MAG or Chief of the Air Section or Army Section or whatever it might be. We give him an overview of security assistance, both foreign military sales grant aid and the peculiarities of overseas functions at a much higher plane and a much higher level. And we can do this in ten class days and we feel we give him not only a complete overview, because many of the people going over as attaches or senior MAG officials aren't necessarily foreign military sales or logisticians and this type thing. A lot of them are infantrymen or artillerymen like myself, or pilots, or what have you. So we feel that they need to have an overview to have an understanding so they can communicate properly with the ambassador or the chief of station or what-

ever he might be, but also so he knows what the people under him, the type training they are receiving in our course so he knows where to go for the information and expertise he needs once he gets overseas.

As with any academic institution, the additional activities as we listed here, and there are probably many more, is for DISAM to become involved. As you all know, in a new institute or organization, you sometimes have to publicize yourself, sell yourself, make it so your product is a wanted product, and because of this, we intend to participate. I must advise that our Policy Guidance Council members are the Director of Defense Security Assistance Agency, the Director of ISA, the DoD Comptroller, the Chairman is the Assistant Secretary of Defense for Manpower Reserve Affairs. You see we have a pretty powerful Policy Guidance Council. Because of that, it has benefited us already, in that we are on the distribution of all State Department and DoD security assistance documentation, message traffic and so on, and because of our requirements, we find it very easy to get in with the people overseas and participate worldwide in conferences, seminars, workshops, that type of thing. We find it very valuable for our instructors, if we are to keep current, maintain close relationships and provide the services and DoD the product they need when their students complete the Defense Institute of Security Assistance Management.

Further down the line, we hope to get involved with DSAA in preparing studies and reports for their consideration in perhaps changing some policy or some methods of operation; and even further down the line, putting out publications that perhaps some of you may see in the future designed for security assistance update for

worldwide publication to keep people aware of changes in legislations, regulations and thinking. So we are going to become involved.

We are going to become involved because we feel we are a unique resource by the interest shown by DoD in our Institute, the fact that we represent all services on our staff and faculty, the fact that we are in an academic environment and it gives us the opportunity to not only teach and research, but a very good opportunity to not only teach and research, but a very good opportunity to be objective in looking out into the field and seeing perhaps what is desirable out there, in time to develop security assistance expertise so that we can become directly involved, again as consultants, and out primary function is to prepare the people in the business for security assistance assignments.

Hopefully some of you will have the opportunity to visit us as students. I know a lot of you from industry and we are close with industry and they are providing us guest speakers who come in and present industry's viewpoint of security assistance. Of course when they do that, they have the normal academic freedom, nonretribution and this type thing, and they really come across and it's amazing, very interesting, as to how they perceive it and as General Edwards pointed out, he said if you get nothing else from this talk, economic considerations are not, I guess, the primary reason for our foreign military sales program. That's true. But it impacts very heavily and it's amazing the insight you get from the various people. The same with the State Department. When they come in and talk about human rights issues and this type thing and DoD people come in and they have to enforce this, it's a good mixture. And it's because of this type of

instruction that we are able to present at DISAM, we are learning alot on staff and faculty to develop material to put out into the field so that you people will have a better understanding for it also.

Thank you for your time and permitting me this opportunity to publicize DISAM and hopefully in the future, we will be seeing you again as a student or participating in one of our workshops. Thank you very much.

SQUADRON LEADER RICHARD GILBERT

AUSTRALIA

Thank you. As you see on your flyer, co-speaker for this session is Peter Shannon from Qantas. I'll explain Qantas' relationship with the Australian Air Force later in the paper, but Peter has been with Qantas for 14 years and been involved with inertial systems since 1968, when he completed inertial training at Woodland Hills in California and also at North Island Naval Air Station. He has several years experience in gyro testing, he received a Bachelor of Electrical Engineering from the New South Wales Institute of Technology in 1972 and received a Master of Engineering Science from the University of New South Wales in 1976. Peter hasn't got a paper to present as such, but some of the questions will obviously hinge around Qantas activities in the repair of gyroscopes and he will join with me for the question period at the end of the talk I'm giving.

The paper as such, was authored by Flying Officer Bruce Hart, who is a project officer from Headquarters Support Command in Melbourne and the complete text of the paper will be in the proceedings so I don't want to go through the full paper and read it word for word. What I'll do is touch briefly on some of the subjects, leave more time for questions and then leave it up to you fellows.

First of all, I'll define in broad terms the RAAF maintenance policy, mention some of the factors that influence the maintenance policy that the RAAF has adopted for maintenance of inertial systems.

The prime principle of the Department of Defense policy is as far as possible all maintenance of operational aircraft is to be kept within the service, that's within the RAAF. Depot level maintenance of training aircraft might go to industry.

Now the aim of that policy is to give the RAAF control of its own effectiveness at all times, particularly in regard to operational aircraft. That includes peacetime, times of industrial unrest and readiness for war in emergency or in war.

The basic principle while highly desirable is not practical for the support -- for the depot level support of equipments like inertial systems and why the excessive large costs associated with depot level support will limit the number of inertial systems and the impact of that type of support would have on the manning structure within the RAAF and the career progression of the skilled technicians that would be required to support that task.

Therefore, with those considerations in mind and coupled with the Australian government's continuing policy to assist progress wherever possible, the Air Force has adopted or changed that policy, the basic policy, to meet those circumstances.

Currently we have two types of aircraft treated with inertial system. That's the F-111 with the air pollutant, I'm sorry, Litton LN-14 and the P-3B with the Litton LN2C, a little plug for Litton there.

With the exceptions of the gyros and the accelerometers, all maintenance of those two systems is carried out by RAAF technicians and in RAAF facilities. The maintenance, the depot level maintenance for the G200 gyro and the G280 gyro is done by Qantas.

And I'll get away from the paper here and explain the relationship between Qantas and the RAAF.

Qantas are a commercial airline, basically, but they are owned by the Australian government. They operate as an independent company. As an obvious extension of that, they also have fairly extensive aircraft and aircraft maintenance facilities. Not only do we put RAAF technicians in the facilities but we pay Qantas as a contractor to perform certain tasks for us. I guess you can summarize that and say that Qantas are Defense Department approved repair agencies.

The next heading is RAAF engineering and maintenance management structure. Right at the top I'd say we have our Department of Defense Air Force Office and for purposes of today's presentation, we can equate that to the Headquarters USAF at the Pentagon. The Department of Defense Air Force Office therefore make the policy and define maintenance philosophy.

Subsequent engineering management is the responsibility of Headquarters Support Command. I guess once again we can relate to the USAF and call it Air Force Systems Command and Air Force Logistics Command.

Within Headquarters Support Command, the responsibility is split between two branches. One maintenance and one engineering. The maintenance branch is concerned primarily with insuring that repair facilities, that is both civilian and RAAF facilities, have the capacity to meet the RAAF repair requirements. This includes supplying the facility with transport equipment, publications, spares assessing -- that applies really back to

the depot level and the lower level maintenance, as well. That's the spares assessment part.

In addition, the maintenance branch continually monitors the repair contractor performance and in the event of shortfalls becoming iminent, they have to come up with a solution to overcome the problem.

It's not mentioned in the paper, but the maintenance branch also has a responsibility for insuring that the contractor or the repair facility has the necessary skill at hand and expertise and therefore, he is also responsible for insuring the training programs are carried out. I might refer that to the fact that both Qantas and the RAAF had training at AGMC early in the Litton program.

The engineering branch, on the other hand, is concerned solely with the engineering and airworthiness standards. They have a project staff and that project staff monitor failure trends and investigate defect conditions, process modifications, maintain publication integrity, develop and improve maintenance procedures and generally administer and coordinate all engineering aspects that cannot be conducted by the operators or the maintenance squadrons.

Included in the support command structure is a resident engineer. Resident engineers are located at each of the civilian contractor's facility and he is there primarily to monitor the contractor's performance and generally liaison between the contractor and the RAAF on any problems or engineering matters. And in that regard, we do have a resident engineer at Qantas.

At the intermediate level facilities for both the F-111 and the P-3B, we operate under what we call a Centralized Maintenance Concept. Now the paper doesn't address what a centralized maintenance concept is, but if anybody is interested, we will be open to questions on that at the end of the paper.

I also have some statistics. I wasn't going to cover them in any detail and I won't do it now, but I thought after the bit of crosstalk there yesterday in the lessons learned session on what is MTBF and MTBR and so forth, I thought it might be interesting to tell you people what MTBF, etc., we are achieving with the LN2C and the LN-14 reporting system.

I'll get on to the problems we are having, or have had. I don't think they are really unique to us. They are probably similar to the same experienced by the U.S. military and other commercial operators. That includes service manning levels, low MTBFs, training expertise, personnel movements and so on.

The most significant of these problems has been the non-availability of serviceable gyroscopes. This position became evident in late '75 and I don't think we've overcome the problem completely yet, in fact I'm sure we haven't.

The shortfalls in the overall program, we exchanged a number of 200 gyros with the U.S. Navy, for the repair of a number of these failed gyros.

Also, we're on the verge of formalizing a consultancy agreement on an FMS case with the USAF, whereby Qantas and AGMC will exchange diagnostic data and will help to give Qantas the capability that they have to achieve.

To further productivity, repair case has been established with AGMC for repair of the F-111 motor and flight assemblies, which Qantas weren't going down that far into the gyro. In addition, Qantas is buying a modern flight test station. Apparently the problem had occurred earlier where they built up gyros only to find out that the motor was U.S. and had to tear it down again.

There's another probably controversial issue that's been addressed in the paper and that covers technical orders. I was going to leave it out, but that also came up yesterday in the lessons learned session, so I thought I would read it as it is here and the words aren't mine, but I've got a few different views on what's said here, but I think it will probably come out later anyhow.

They say a significant point that has arisen is that USAF technical orders in use at Qantas were not those being used by the AGMC and over many years AGMC had developed and refined the techniques first published in the T.O.s to such a degree that Qantas was severely handicapped when comparison was made between the two facilities' procedures. So significant were the differences, that Qantas was taking an average six to seven weight shaves to balance a gyro, AGMC were averaging three or four.

In general, the problems we've had at the intermediate level facilities are less significant than that at the depot level and they have not contributed to any reduction of operation effectiveness.

On the subject of projected capability, the RAAF will take

delivery of the C-130 and the P-3C next year. Both of these aircraft will be fitted with inertial navigation systems. The C-130 actually will be the Litton 72R and the P-3C will be the ASN-94 from Kearfott. In both of these cases, the RAAF will be doing the intermediate level maintenance for both systems, however, the gyros, at least at this stage, the gyros will be coming back to the States for depot level support.

And in conclusion, we say that while we are a small operator, we consider that we have built up a level of expertise and knowledge commensurate with the operational objectives of the RAF service, however, we are presently in a position where we must rely on the resources of Australian industry and that is these agencies which have total support and repair and maintenance of existing inertial systems.

A record of achievement in maintaining inertial equipment will insure the growth of inertial system acquisitions for future RAAF aircraft and might ultimately lead to the development of a capability for complete autonomy. Thank you.

# MAINTENANCE OF INERTIAL NAVIGATION SYSTEMS BY THE ROYAL AUSTRALIAN AIR FORCE

BY

FLYING OFFICER B.M. HART

## INTRODUCTION

1. The purpose of this paper is to give the Eleventh Joint Services Data Exchange for Inertial Systems Conference a broad picture of the RAAF's present and projected capability to maintain military Inertial Navigation Systems (INS) and to explain the methods employed by the RAAF to achieve operational status of INS equipped aircraft. The paper will cover aspects of RAAF maintenance policies affecting INS equipment and will describe the management structure of the RAAF that is used to ensure that operational objectives are achieved. In addition, some statistics will be given to allow JSDE members to make a comparative assessment of the RAAF's effectiveness.

### Background

2. Before proceeding, some knowledge of the RAAF's maintenance policies will be imparted along with the factors influencing the final INS equipment maintenance policies adopted by the RAAF.

3. The prime principle of Department of Defence policy is that (as far as possible) maintenance of operational aircraft is to be kept within the Service while the Depot Level Maintenance (DLM) of training aircraft may go to industry. The aim of this policy is to maintain the effectiveness of the RAAF in peace time, times of industrial unrest, in readiness for war, in emergency and in war (1). This basic principle, although highly desirable, is inappropriate when applied to the Depot level support of the RAAF's INS because:

a. the excessive life cycle cost associated with depot level support of a limited number of INS equipments, and

b. the impact that total support would have on the RAAF's manning structure and on the career structure of the skilled technicians required for such tasks.

Therefore with these considerations in mind, coupled with the Australian Government's continuing policy to assist local industry wherever possible, Air Force Office policy has been adapted to meet the circumstances.

4. The RAAF currently has two aircraft types fitted with Inertial Navigation Equipment; the F111C fitted with Litton LN14 and the P3B Orion fitted with Litton LN2C. To support the F111C aircraft, we have 14 spare Stabilized Platform Units (SPU) and 14 spare Navigation Computer Units (NCU) and for the P3B Orion aircraft we have 6 spare Gyro Assemblies and 6 spare NCUs. With the exception of Gyroscopes and accelerometers, all maintenance is carried out by RAAF personnel at RAAF maintenance facilities. Both the G200 and G280 gyroscopes, fitted to LN2C and LN14 respectively, are overhauled under contract by QANTAS.

/RAAF ENGINEERING

(1) DI(AF) Tech 18/5 paragraphs 5 and 7

## RAAF ENGINEERING AND MAINTENANCE MANAGEMENT STRUCTURES

5. After having made the policies and defined the maintenance philosophies, all aspects of management of INS equipments is delegated by Air Force Office to Headquarters Support Command (HQSC). Within HQSC, management responsibilities are divided into two Branches: Maintenance and Engineering.

### Maintenance Management

6. The Maintenance Branch is concerned primarily with ensuring that the overhaul facility has the capacity to meet the RAAF's overhaul requirements each year. This includes supplying the facility with Ground Support Equipment (GSE) and publications, and assessing the requirements for spares and higher assemblies for use by both the overhaul facility and other lower level maintenance facilities. In addition, the Maintenance Branch continually monitors arising rates and contractor performance to prevent short falls occurring. In the event of short falls becoming imminent, the maintenance branch will investigate and pursue other avenues of supply and maintenance to meet the requirements.

### Engineering Management

7. The Engineering Branch is concerned solely with:

a. maintaining and improving engineering standards to meet the operational requirements of the equipment, and

b. ensuring that the airworthiness standards of all aircraft are not jeopardised.

8. To carry out this task, Project Staff:

a. monitor equipment failure trends,

b. investigate defect conditions,

c. process modifications to INS equipment GSE and ATE,

d. maintain publication integrity,

e. develop or improve maintenance procedures, and

f. generally administer and co-ordinate all engineering aspects that could not normally be conducted by the aircraft operators or maintenance facilities.

9. Included in the HQSC structure is a RAAF Resident Engineer whose task is to:

a. monitor standards at the contractor's facility,

b. recognize potential production problems,

c. make decisions to overcome or alleviate any problems, and

d. liaise between the contractor and RAAF and keep the RAAF up to date on all aspects affecting the Engineering and Maintenance Branches.

/Field Management

### Field Management

10. Both Intermediate Level Maintenance (ILM) facilities that support the F111C and P3B Orion operate under the centralised maintenance concept. In the case of the F111C, an Avionics Engineering Section (AVES) manned by qualified engineers is established to cope with the majority of engineering problems that arise. The AVES cell is then able to make recommendations to HQSC. In addition, the AVES cell carries out specific engineering tasks as directed by the parent command headquarters. These tasks in the main consist of evaluations to improve performance and standards and often result in updates or changes to software to improve test station programmes, development or procurement of new test equipment and improved servicing techniques.

## MAINTAINABILITY OF INS EQUIPMENTS

11. To describe the RAAF's level of effectiveness in maintaining the operational status of the P3B and F111C, an outline will be given of the RAAF's maintenance requirements to meet the current flying commitment.

### F111C and P3B

12. Currently the Mean Time Between Removals (MTBR) of the LN14 SPU is about 97 hours and the MTBR of the NCU is 45 hours. However, with a Nil Fault Found (NFF) rate of 25% for the SPU and 35% for the NCU, the Mean Time Between Failures (MTBF) calculations are 130 hours for the SPU and 73 hours for the NCU. ILM Maintenance manhours spent per flying hour are in the region of .8 hours. DLM Maintenance manhours increase this figure to a total of 2.5 maintenance manhours per flying hour to support the LN14 INS. The LN2C presents a similar picture with Gyro Assembly MTBR of 85 hours and NCU MTBR of 63 hours. ILM maintenance manhours represent 1.5 hours per flying hour with an additional 1 maintenance manhour per flying hour for DLM Support, giving a total 2.5 maintenance manhours per flying hour to support the LN2C INS.

### Gyroscopes and Accelerometers

13. The MTBF of the G280 gyroscopes is currently 240 hours and the G200 MTBF is 400 hours. The MTBF of the motor and float assembly for the F111C is 260 hours and for the P3B is 340 hours. MTBF of the accelerometer fitted to F111C is 600 hours and for the P3B is 800 hours.

14. The preceeding statistics give an indication of the RAAF's performance and even though this situation has been tolerated, it has not been without reservations. Comparisons have not been made with the performance of other operators' equipments mainly because such comparisons are difficult to make without time consuming research and in most instances yield very little benefit. Furthermore, the RAAF situation is associated with peculiarities not likely to be experienced by the majority of overseas operators.

## SIGNIFICANT PROBLEMS

15. Service manning-levels, low MTBFs, training, expertise, personnel movements and unforeseen circumstances have all had an effect on the RAAF's INS maintenance. However, the most significant problem to face the RAAF has been the non-availability of serviceable gyroscopes. This situation became very apparent in the latter stages of 1975 and to date has not been completely overcome.

/Overhaul Support

## Overhaul Support by US

16. Due to short falls in our overhaul programme, the RAAF exchanged a quantity of G200 gyroscopes with the USN and also arranged to have 20 G280 gyroscopes repaired by the USAF Aerospace Guidance and Meterological Centre (AGMC) thus relieving the immediate critical shortages. Following discussions with USAF, RAAF and QANTAS, Air Force Office has asked our Air Attache to arrange a Government to Government FMS case to enable QANTAS to approach the AGMC direct. This avenue for exchange of information will provide QANTAS with improved diagnostic facilities and enhance their overhaul potential. We see this type of liaison as being important in the support of our INS.

17. A significant point that has arisen is the fact that USAF technical orders in use at QANTAS were not those being used by the AGMC and that over many years the AGMC had developed and refined the techniques first published in the TOs to such a degree that QANTAS was severely handicapped when comparisons were made between the two facilities' procedures. So significant were the differences that where QANTAS was taking on average 6 to 7 weight shaves to balance a gyro, the AGMC was averaging three to four weight shaves. This, is an example of how direct contact between overhaul facilities is of major importance.

18. To further aid productivity, a repair case has been established with AGMC for F111C motor and float assemblies. In addition, a motor and float test station is being acquired for QANTAS to prevent re-occurrences of the situations where many man-hours are spent building up a gyro only to find the motor unserviceable. The receipt of unserviceable spares such as gimbal rings, outer gimbal pivots and float assemblies is currently being investigated although this problem is not quite so significant as, with the exception of float assemblies most unserviceabilities can be detected by stringent inspection before use. Nevertheless, the possibility of receipt of unserviceable spares imposes extra workload and delays the overhaul facility to the detriment of production.

## RAAF Facilities

19. Problems at the RAAF intermediate level facilities are less significant and have not contributed to any reduction of operational capability. In fact, laborious measures and matching combinations are pursued to ensure that gyroscopes returned to the overhaul facility are totally unserviceable. This is borne out by the non-existant NFF rate of gyroscopes returned to QANTAS. Although time consuming, the measures are acceptable and necessary to achieve maximum utilization of spare gyros. Some unserviceabilities have occurred with P3B Gyro Assemblies that are attributable to the age of the equipment, and have resulted in azimuth assembly slip ring changes that account for 300 man-hours per item. Together with the equally time consuming maintenance of the NCU DC Amplifiers, the LN2C INS is seen as a far less maintainable system than the LN14 and reflects the different levels of technology in use. However, from the MTBFs, the more docile environment of the Orion can be seen to result in better performance of gyroscopes, floats and accelerometers.

## PROJECTED CAPABILITY

20. The RAAF will take delivery of our first C130H and P3C aircraft during 1978, both of these aircraft types will be equipped with Digital Inertial Navigation Systems, the Litton 72R for the C130H and the Singer-Kearfott AN-ASN 84 for the P3C. In both cases, the RAAF will perform ILM,

/however,

however, for some items including the Gyros DLM will be carried out in the US. The cost of supplying DLM support for such a small quantity of different, highly specialised equipments is not justified.

## CONCLUSION

21. Although suffering from the 'small operator syndrome', the RAAF has built up a level of expertise and knowledge commensurate with the operational objectives of the Service. RAAF is presently in a position where we must rely on the resources of Australian industry and overseas agencies to achieve total support in the repair and maintenance of existing INS.

22. The RAAFs record of achievement in maintaining INS equipment will ensure the growth of INS acquisitions for future RAAF aircraft and may ultimately lead to complete autonomy.

MAJOR PHILIP JACKSON

CANADA

I haven't been in avionics very long. I've got one other Canadian representative down with me and I'd just like to introduce him because he's going to give me a hand with the question period, Major Clyde Sorenson. He was born in Chicago in the 40s. He has a Bachelor of Electrical Engineering from Purdue. He's presently the Chief of Navigation Subsystem Engineering at National Defense Headquarters. His two previous assignments were flight test engineer for inertial systems at Holloman Air Force Base and in the gyro program at Wright-Patterson Air Force Base. Flies, as you probably got, as an officer in the United States Air Force and he knows more about what the Canadian Parliament in 1921 and the Canadian Parliament passed an act in 1967 to abolish it and integrated us with the Canadian Army, Royal Canadian Navy so it became the Canadian Forces and the RCAF ceased to exist at that time.

I'm going to give you a broad overview of the Canadian organization and Canadian national organization is very similar to the American so I'm just going to touch the highlights of it and show how we've organized to satisfy our own -- how we see our responsibilities for our own security, which is really tied into North American security, and once again tied into Western security.

Just in the inertial nav business, we have one system, it's the Litton LN-3 at the present time. We'll be getting the LN-33 with the purchase of the long-range patrol aircraft, which is a

P-3C with basically largely Canadian avionics in it. The LN-3, we have 100 of them installed right now. They are in the CF-104 Star fighter aircraft and there are approximately 60 aircraft in Germany and 40 aircraft in Alberta.

The maintenance organization in the Canadian Forces and the engineering organization are tied closely together. About four years ago, National Defense Headquarters was reorganized to eliminate the separation of engineering and maintenance, which came together at the Brigadier General level. They now come together at the Lieutenant Colonel level and Clyde and I work for the same boss. He looks after the engineering side and design side and the acquisition side and I look after the maintenance side.

The terms of setting up a maintenance program or developing a maintenance concept for a system, one of the principal objectives as far as the depot level is concerned is to maintain a Canadian self-sufficiency and support. That becomes increasingly difficult as systems get more and more complex and where Canadians were designing and building their own aircraft and aero engines in the early 50s, we are slowly backing out of it. We still design and manufacture a lot of our own avionics.

So we had when we set up our maintenance -- one way that we can keep a contractor going is to give him our depot level work and that's basically what we do. So the Canadian contractor is also the manufacturer -- it's Litton -- the company is in Toronto. We had the depot level like expertise in Toronto, we had two operating squadrons in Alberta, which is 2500 miles West of Toronto. We had three operational squadrons in Germany, which is about 5500 miles east of Toronto, and with the large distance

between units and with the potential for damage in shipment, we decided to do what we've done on air frame programs, and that is send the contractor to the operating unit. So we set up a Litton technical support group in Alberta and one in Germany. The technical support groups are managed by Litton. The contract is with Litton in Toronto. The technical support groups are managed by Litton. The contract is with Litton in Toronto. The technical support groups are managed by on-site Litton people. They are co-manned by Canadian forces and Litton personnel, about equally. The Germany technical support group has six civilian and six contractor personnel and the Alberta facility has three military and two civilians.

This has worked out real well. It has been in effect for some time. It has a couple of other advantages. With the small number of systems we use, we have closer integration of expertise or experience at the field level and the depot level because they are co-located. We find that another thing that happens if the depot level at the base, of Litton's group at the base in not fully employed on third line work or depot level work, they do assist with second line work. If the Litton activities get over-worked, we will move military personnel in to work for the Litton supervisors, so we tend to even out the workload and we also tend to even out the expertise involved so that the people in the field have a better idea of what is being done at contractor level and contractor vice versa.

About 80 percent of all depot level repairs on the LN-3 are done on-site at the two operating units. The other 20 percent are principally associated with repairs to the gyro platform itself.

There are no facilities there, clean room facilities for working on these.

At the same type of organization, we are going to be getting 18-hour PA aircraft, that's the P-3C, C standing for Canada, I guess. It will have the LN-33, the first three will be manufactured in the United States, but the following 15 will be manufactured by Litton Canada. The terms of our handling of inertial systems, but we've lumped them together with gyroscopic systems and the other principle we have is when we look at our problems is the gyro heading reference system and we've got 200 of these installed in the seeking helicopters which operate off of destroyers and the CF-5 aircraft, which is once again the Canadian manufactured version of the F-5 and the tracker, which is the Canadian manufactured version of the CS-2F.

I think I can sum up our problem in this quite easily -- it costs us about three million dollars a year to maintain those 300 systems and that's our contracting cost. Two million of that is spent on the LN-3 and the other million is spent on the gyro heading and reference system.

So the type of problems that we have are exactly the same types of things that have been discussed for the same types of things that have been discussed for the last two or three days. We really recognized this problem just recently, or the magnitude of it, and decided that we had to do something and we set ourselves a very ambitious objective of cutting down our costs by about 25 to 30 percent in our overhaul end. And to do that, we have meetings almost like this. We meet every six months to discuss gyro-based maintenance problems or gyro-based

system maintenance problems. We're taking basically a three-pronged approach. One is to go out and tell people that they are delicate and that's a lesson I guess that we are relearning. It was mentioned earlier because we went out in the field, to the techs in the field and we got about a 20-year-old Corporal or Sergeant and he says, gee, where have you guys been for the last 20 years because that's what you were preaching when I enlisted and I haven't heard of it since.

We are looking at packaging and we are working closely with the similar people in the United States Air Force on that and we are looking at our overhaul and maintenance procedures. We have a lot of component changing occurring at all levels of maintenance which is purely speculative because we don't have the test equipment to verify whether or not the component is serviceable or not and the only way we have of verifying it is to remove it. What we think is serviceable, because we get that off of the contractor and that I guess is a greater problem really is that more serviceable than the one we took out of the component?

We are faced with the same problems in getting information, defining what the problem is, zeroing in on it and defining a course of action on it. Our information system, we have the same types of problems. We are refining our maintenance management information system so that it's going to hold component histories by serial number on it rather than providing broad management general summaries of information on systems performance.

I think that's the basic overview on our organization and the way we've gone about maintenance. We do do our own and we

still do some manufacturing in that area. Any questions?

(INAUDIBLE QUESTION FROM AUDIENCE.)

SORENSON: The answer to your question is basically yes. He was wondering what is the air crew criteria, I guess, for writing up a problem with the inertial set. It's basically the same criteria that the U.S. Air Force uses. I guess we are trying to get away from that a little bit more in tracking system performance, to base reliability or maintenance problem on more than one flight. Something similar to what we did with rivet gyro and Neal Thomas has done an awful lot of work on that in the LN-12 and we're trying to bring that over into the LN-3.

(INAUDIBLE QUESTION FROM AUDIENCE.)

JACKSON: The question was in using military and civilian as co-located with the operation being run by the civilian, does the contractor rebate us for the military personnel that they use? No, the contractor is paid just for the work that he does and there is no provision in the contract for the amount of military work that goes in. The reason here is basically that the only time military assists is if the contractor is overworked. It's virtually an arrangement that's worked out at the base between the operator, the maintenance people on the base and the Litton supervisor. It's a fixed-price contract. The only thing that's variable is we pay all TDY for the contractor personnel.

The control on it is a monthly report from the contractor which lists by serial number all the work that is done.

(INAUDIBLE QUESTION FROM AUDIENCE.)

SORENSON: Did everybody hear the question? Do we do below

float level repairs on gyros? And the answer is the service doesn't, it's not done at the operating units. It's sent back to Litton Toronto where they do the work.

(INAUDIBLE QUESTION FROM AUDIENCE.)

JACKSON: They were just mentioning what the organization between Litton and the service does; it's not only with Litton that we have these, we have these with our air frame overhaul contractors as well as with our avionics overhaul contractor, so we tend to put supervisory level people quite close and parallel to our own supervisory level people and working people in the Canadian Forces. And what we have is a fairly constant flow of communication at that level, at the supervisory level and at the lower intermediate management levels as well. What you find between the contractor people and the service people in the field, they talk as a team and I think that probably describes it to me best of all. Long after many of the contractor people go back to their parent company, they still have this concept of having the service and our civilian contractors -- our relationship with them is all part of one team and I think that the organization that we have contributes to that and emphasizes that fact, that we're in business together and it puts the depot and the contractor right on the front line as well. They see what the tech in the field has to do, how he has to do it and the pressures that are on him to do it and it works out real well.

(INAUDIBLE QUESTION FROM AUDIENCE.)

JACKSON: No, sir, I'm not aware of any. I'm not aware of

any. I'm not aware it's a problem -- well, we have had one problem in negotiating the benefits -- the number of services benefits that the civilian contractor gets, access to service flights, access to our exchange system, things like that. We have no position on it, as long as the contractor, when he comes to negotiate the contract wants to talk those things. If it is negotiated as part of the contract, generally we will extend those privileges as part of the negotiation. But I'm not aware of any other problems.

MAJOR JOSEPH RON
ISRAELI AIR FORCE

## CRITERIA FOR SERVICEABILITY OF PLATFORMS

1. A manufacturer of an IMU defines criteria for acceptance of an IMU. From our experience, we know that this is not sufficiently detailed to enable the technician to decide whether the IMU is serviceable. The problem would be very simple if the phenomenon in this area were either black or white. To our dismay, most of the problems are in the gray region.

2. Better monitoring of the performance of the IMU became more important as the Analog System Circuitry combined with the platform was replaced with a high precision digital processor.

3. When we talk about error analysis for a system with analog components, we can see that the errors of the other parts of the system are equal to that of the IMU. In this case, we are as concerned with the accuracy of the other components as we are with the IMU. There is no benefit gained by improving the monitoring of the IMU only.

4. We have defined a set of criteria for three levels of maintenance:

   a. Flight Line

   b. Field (Or Intermediate)

   c. Depot

5. I will speak about the criteria for flight line and depot. The field criteria is a mixture of both.

6. Flight Line

a. In the criteria for the flight line, there is a strong dependence upon the flight history of the aircraft. We keep a record of the final velocities in the X and Y axes; the total G.S.; and of course, the navigation error at the end of the flight.

b. The main purpose of the criteria is to reduce to the minimum, the number of replacements, for these reasons:

(1) A maintenance action can cause a new failure.

(2) There is some uncertainty about the performance of the new platform so we want to be very sure before a replacement is made.

EXPLANATION OF THE LAST STATEMENT: We know that the behavior of the platform under dynamic conditions of the flight may not be the same as under static conditions on-ground as was mentioned yesterday when we talked about CERT.

c. Maintenance Actions in Flight Line

(1) Reading out the constant values from the memory to see if there was a change during the flight.

(2) Drift Runs (Shuler Test).

(3) Short Automatic Calibration.

(4) Manual calibration according to some "rules of thumb".

(5) IMU replacement.

(6) Nothing (from my experience it happens to be the best thing to do sometimes.)

PRESENTATION OF THE FIRST SLIDE WITH A DEFINITION OF PARAMETERS AND RANGES OF ERRORS.

d. The definitions of $V_1$, $VT_1$ and $D_1$ are based upon the actual results we had in the field in 65%-70% of the flights ($\sim$ IG). $V_2$, $VT_2$, and $D_2$ include more than 90%. Ranges C, D are the remainder.

e. We usually relate to Ranges C, D as an occurrence which has low probability to repeat. However, when the occurrence is repeated, we assume that there is a high probability to find a hard failure. (You will see this philosophy in Ranges C and D).

f. The maintenance actions we recommend and the records we keep could not be performed unless the equipment had been built according to this maintenance concept.

PRESENTATION OF THE REST OF THE SLIDES

7. <u>Depot</u>

a. We had a problem that the intermediate level and the depot were not using the same test equipment to verify the failure and to make the final checks. It happened to us that an IMU which was serviceable according to the depot procedures was rejected by the field.

b. We determined the Shuler Test as the final criteria for the depot.

c. The criteria is based on the results of three consecutive drift runs (Shuler Tests) of 84 minutes each.

d. The criteria in the depot case took into consideration the money aspect because of the price of the inertial sensors (gyros and accelerometers). One should decide how much he is ready to invest in order to get the best performance. This includes selection of sensors in order to receive the desired performance.

CRITERIA FOR SERVICEABILITY OF PLATFORMS

DEPOT CRITERIA

Definitions

$V_{P1}$ - the peak value of the velocity in a drift run (Shuler Test).

$V_{PA}$ - the average value of the peak velocities (absolute values).

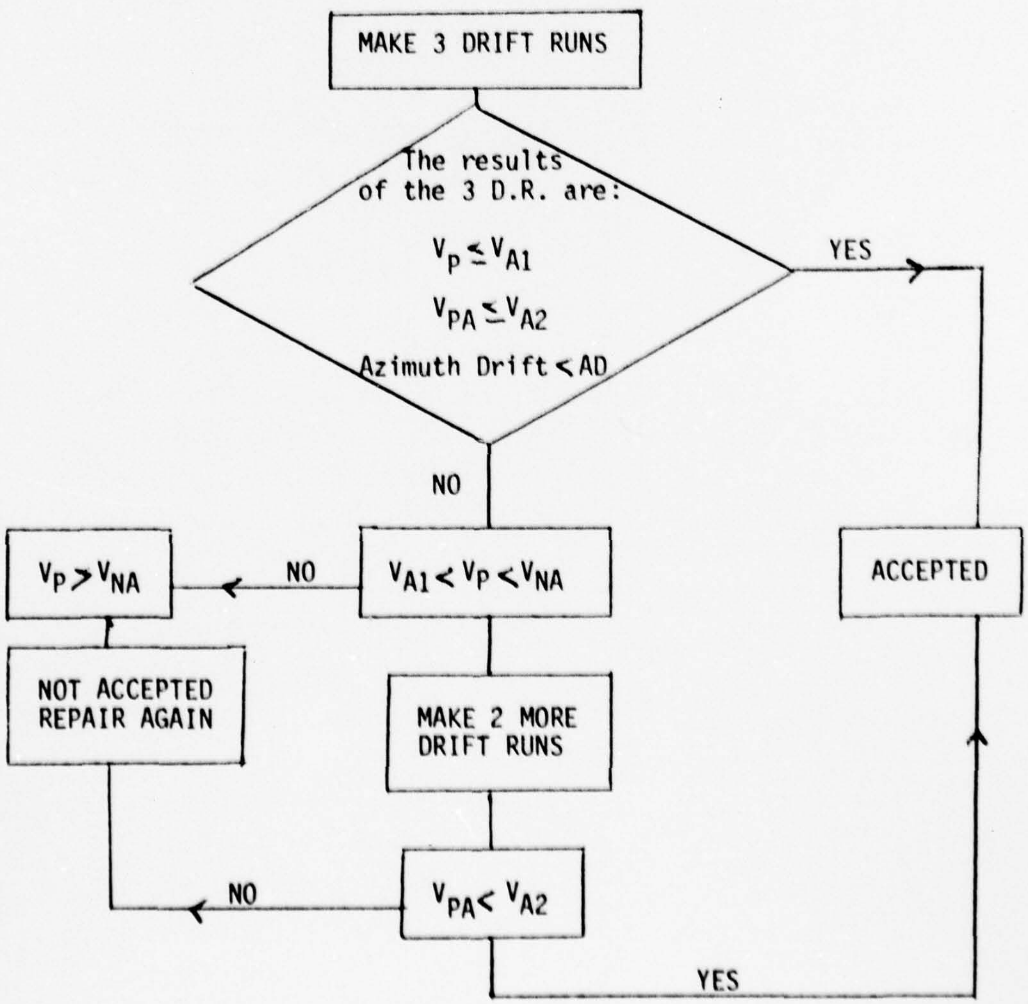
$V_{A1}$ - maximum permitted value of $V_P$ (peak velocity).

$V_{A2}$ - maximum permitted value of $V_{PA}$ (average velocity.)

$V_{NA}$ - velocity not acceptable.

AD - maximum azimuth drift permitted.

FLOW CHART



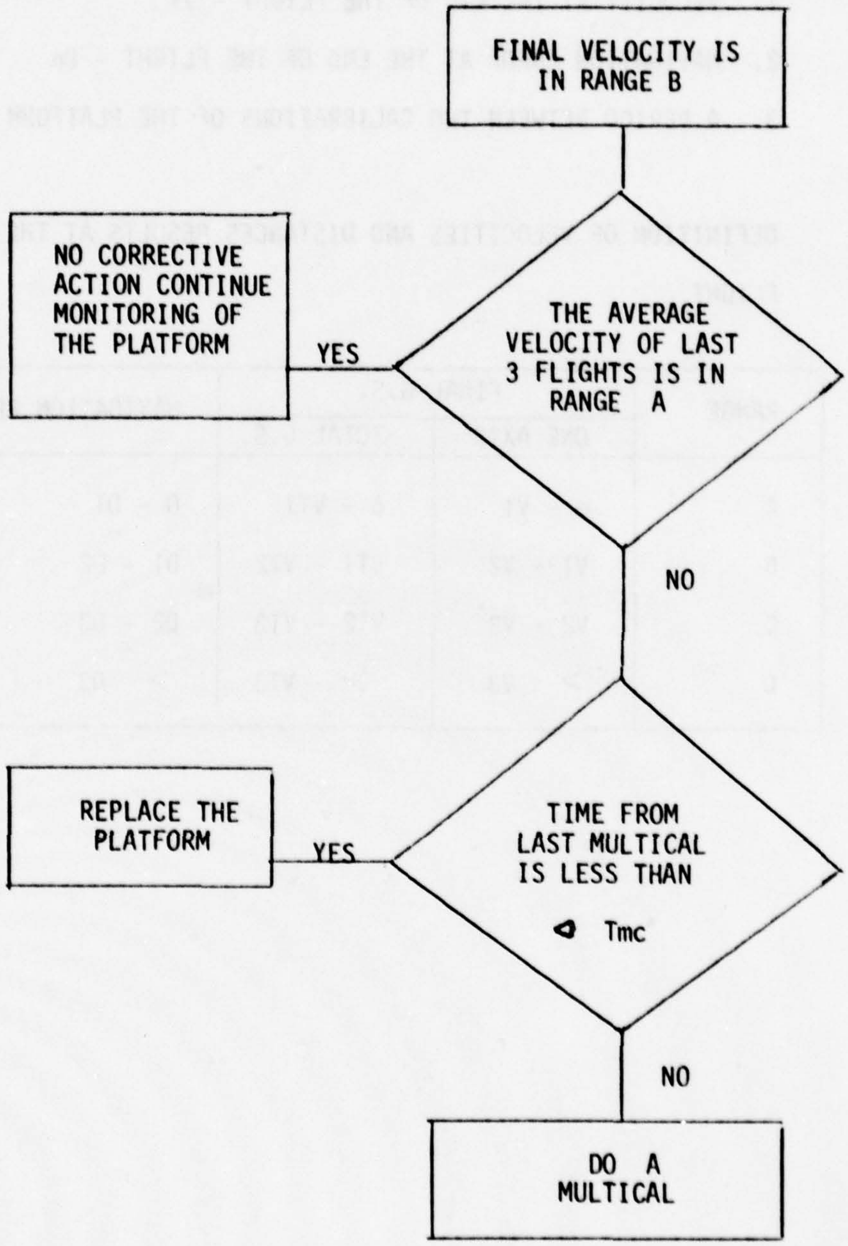
## DEFINITION OF PARAMETERS

1. VELOCITY AT THE END OF THE FLIGHT - Vf
2. NAVIGATION ERROR AT THE END OF THE FLIGHT - Dn
3. A PERIOD BETWEEN TWO CALIBRATIONS OF THE PLATFORM CONSTANTS - $\Delta$Tc

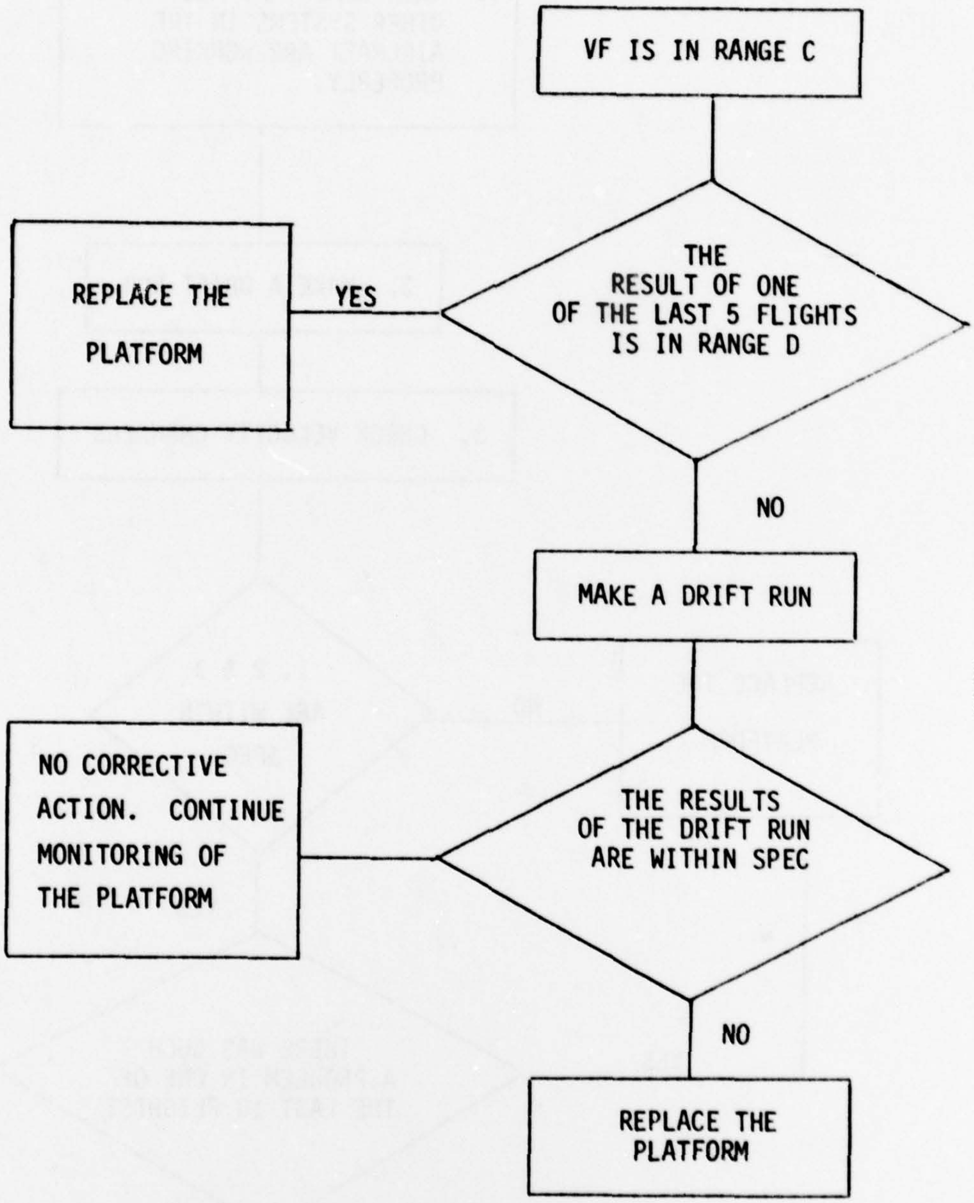
DEFINITION OF VELOCITIES AND DISTANCES RESULTS AT THE END OF THE FLIGHT

| RANGE | FINAL G.S. | | NAVIGATION ERROR |
|---|---|---|---|
| | ONE AXIS | TOTAL G.S. | |
| A | o - V1 | o - VT1 | 0 - D1 |
| B | V1 - V2 | VT1 - VT2 | D1 - D2 |
| C | V2 - V3 | VT2 - VT3 | D2 - D3 |
| D | > V3 | > VT3 | > D3 |

## RANGE B

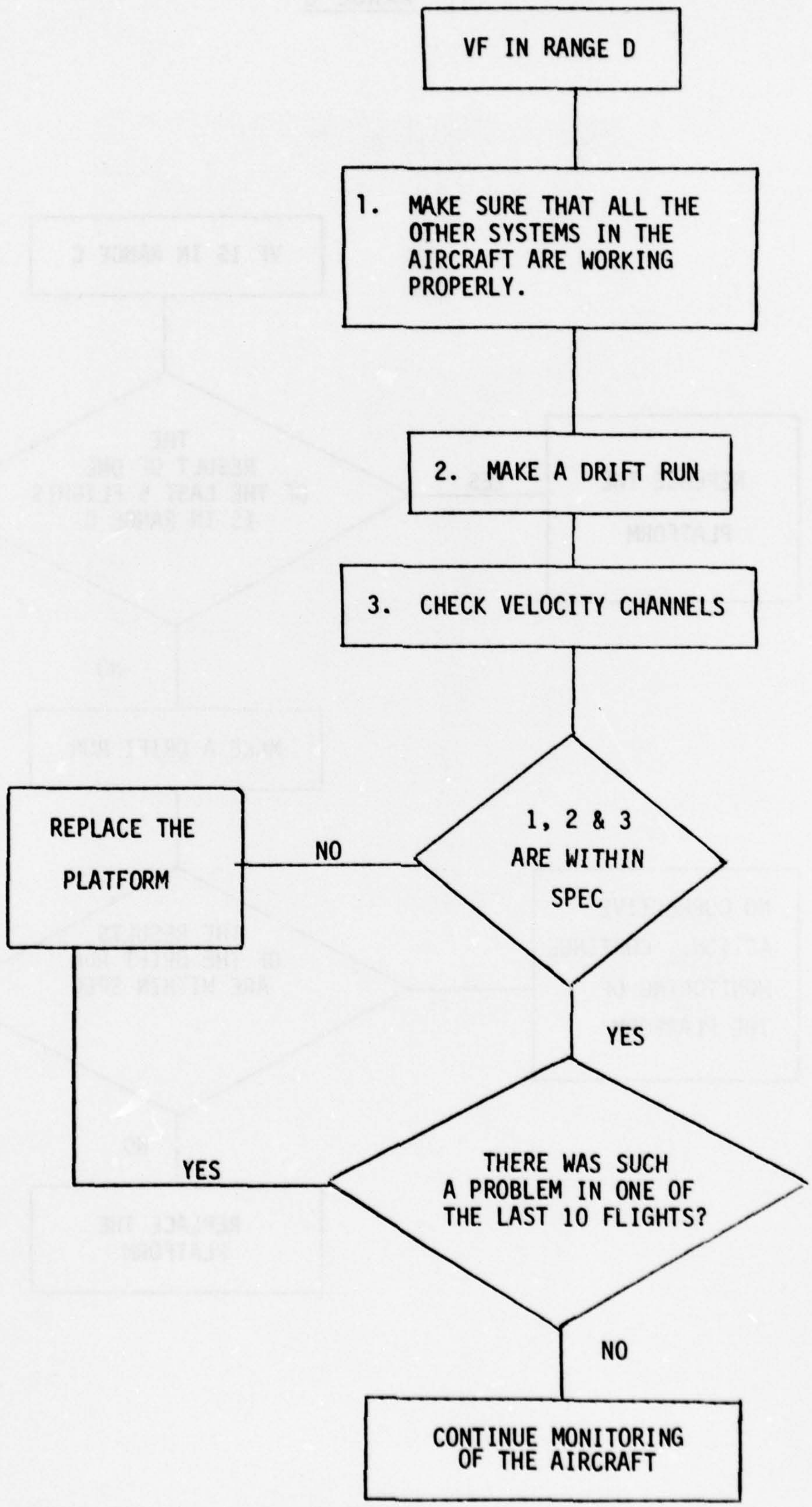

FINAL VELOCITY IS IN RANGE B
THE AVERAGE VELOCITY OF LAST 3 FLIGHTS IS IN RANGE A
YES
NO CORRECTIVE ACTION CONTINUE MONITORING OF THE PLATFORM
NO
TIME FROM LAST MULTICAL IS LESS THAN Δ Tmc
YES
REPLACE THE PLATFORM
NO
DO A MULTICAL

RANGE C



VF IS IN RANGE C
THE RESULT OF ONE OF THE LAST 5 FLIGHTS IS IN RANGE D
YES
REPLACE THE PLATFORM
NO
MAKE A DRIFT RUN
THE RESULTS OF THE DRIFT RUN ARE WITHIN SPEC
NO CORRECTIVE ACTION. CONTINUE MONITORING OF THE PLATFORM
NO
REPLACE THE PLATFORM

RANGE D



VF IN RANGE D
1. MAKE SURE THAT ALL THE OTHER SYSTEMS IN THE AIRCRAFT ARE WORKING PROPERLY.
2. MAKE A DRIFT RUN
3. CHECK VELOCITY CHANNELS
1, 2 & 3 ARE WITHIN SPEC
NO
REPLACE THE PLATFORM
YES
THERE WAS SUCH A PROBLEM IN ONE OF THE LAST 10 FLIGHTS?
YES
NO
CONTINUE MONITORING OF THE AIRCRAFT

SPECIAL SUBJECT PRESENTATIONS

SESSION KEYNOTER AND CHAIRMAN

WILLIAM B. MAXSON, BRIGADIER GENERAL, USAF
WASHINGTON D.C.

KEYNOTE ADDRESS

SESSION VI - SPECIAL SUBJECTS PRESENTATION

I AM PRIVILIGED TO BE ABLE TO ADDRESS THE SESSION THIS MORNING. AS I REVIEWED THE PAPERS TO BE PRESENTED: I WAS ASTOUNDED BY THE DIVERSITY OF SUBJECT TO BE DISCUSSED. IT IS NOT EASY TO TIE TOGETHER THE SUBJECT OF AIR FORCE AVIONICS POLICY, TACTICAL INERTIAL GUIDANCE AND INTERNATIONAL LOGISTICS. YET THERE IS A THREAT OF CONTINUITY THAT BUNDLES THESE TOPICS TOGETHER - DOLLARS - WHAT POLICIES WILL BE INSTITULED WITHIN THE AIR FORCE TO REDUCE THE SPIRALLING COST OF AVIONICS - ALREADY COSTING 10-30% OF THE TOTAL AIRCRAFT COST. WHAT MANAGEMENT METHODS ARE BEST USED TO REDUCE THE LCC OF INERTIAL NAVIGATION SYSTEMS. WHAT NEW TACTICAL INERTIAL GUIDANCE SYSTEMS OFFER IN TERMS OF PERFORMANCE AND COST. WHAT ARE THE INTERNATIONAL LOGISTICS PROBLEMS AND THEIR ATTENDANT COST IMPACTS.

# SESSION VI

# SPECIAL SUBJECT PRESENTATIONS

## KEYNOTE ADDRESS

BY

BGEN WILLIAM B. MAXSON

WHAT I WOULD LIKE TO DISCUSS WITH YOU ARE SOME THOUGHTS, CONCERNS AND PERCEIVED OPPORTUNITIES REGARDING THE IMPACTS OF ADVANCING TECHNOLOGY ON OPERATIONAL SYSTEMS FOR POSITION, NAVIGATION AND WEAPONS DELIVERY. AS MANY OF THE SESSIONS OF THIS CONFERENCE HAVE DEMONSTRATED, WE ARE APPLYING OUR SCIENTIFIC KNOWLEDGE TO ACHIEVE ECONOMIC, OPERATIONAL, AND PERFORMANCE IMPROVEMENTS. WE IN R&D ARE TAKING POSITIVE ACTION TO IMPROVE MISSION SUCCESS WITH PROGRAMS UNDER DEVELOPMENT THAT WILL PROVIDE THE OPERATORS WITH HIGH QUALITY INFORMATION IN A TIMELY MANNER.

# USAF

# NAVIGATION

# PLANS

# OVERVIEW

I HAVE BROKEN THE BRIEFING DOWN INTO THE FOLLOWING FIVE AREAS. FIRST WE WILL COVER THE MILITARY REQUIREMENTS FOR NAVIGATION FOLLOWED BY A REVIEW OF THE EQUIPMENTS IN A FUTURE NAVIGATION SUITE AND THEIR RELATIONSHIP TO THE OVERALL AVIONICS ARCHITECTURE. THIRD WE WILL FOLLOW WITH A SHORT REVIEW OF SEVERAL MAJOR NAVIGATION PROGRAMS WHICH WILL HAVE A MAJOR IMPACT ON NAVIGATION EQUIPMENT AND THEN REVIEW THE COMING EVOLUTION IN NAVIGATION EQUIPMENT. I WILL CONCLUDE WITH A SUMMARY OF AIR FORCE THRUSTS IN NAVIGATION.

# OVERVIEW

- REQUIREMENTS
- AVIONICS ARCHITECTURE
- MAJOR EFFORTS
- NAVIGATION EQUIPMENTS
- CONCLUSIONS

## REQUIREMENTS

THIS IS A LIST OF THE AIR FORCE REQUIREMENTS FOR NAVIGATION. A QUICK REVIEW REVEALS THAT NO SINGLE PIECE OF EQUIPMENT IS CAPABLE OF SATISFYING ALL OF THESE REQUIREMENTS. THEREFORE SEVERAL PIECES OF EQUIPMENT MUST BE MADE TO WORK IN CONCERT TO SATISFY THESE REQUIREMENTS. I WON'T DISCUSS EACH ONE OF THESE-BUT WILL COVER THE FIRST AND LAST. THE FIRST TO HEAD MOST ANY LIST OF MILITARY REQUIREMENTS IS INCREASED ACCURACY FOR TARGET LOCATION. WE MAY FINALLY BE ON THE VERGE OF ELIMINATING THIS REQUIREMENT OR DESIRE WITH THE ADVENT OF GPS AND ITS 30 FOOT POSITION ACCURACIES. INFACT GPS WILL FULFILL ALL THE REQUIREMENTS EXCEPT THE LAST. "SELF CONTAINED". SINCE THERE IS NO WAY TO GUARANTEE THE AVAILABILITY OF EXTERNALLY REFERENCED NAVIGATION SYSTEMS IN WARTIME. OUR FLEET IS EQUIPPED WITH SELF CONTAINED NAVIGATION SYSTEMS WHICH CAN BE UPDATED USING EXTERNALLY REFERENCED NAVIGATION SYSTEMS. A REVIEW OF THESE REQUIREMENTS LEADS UP TO A DISCUSSION OF THE MAKE-UP OF THE FUTURE NAVIGATION SUITE.


REQUIREMENTS
• INCREASED ACCURACY
• THREE DIMENSIONAL
• COMMON GRID
• WORLD WIDE COVERAGE
• RESISTANT TO ENEMY ACTION
• DENY ENEMY USE
• PASSIVE & UNSATURABLE
• CONTINUOUSLY AVAILABLE
• REAL TIME RESPONSE
• SELF CONTAINED

## AVIONICS ARCHITECTURE

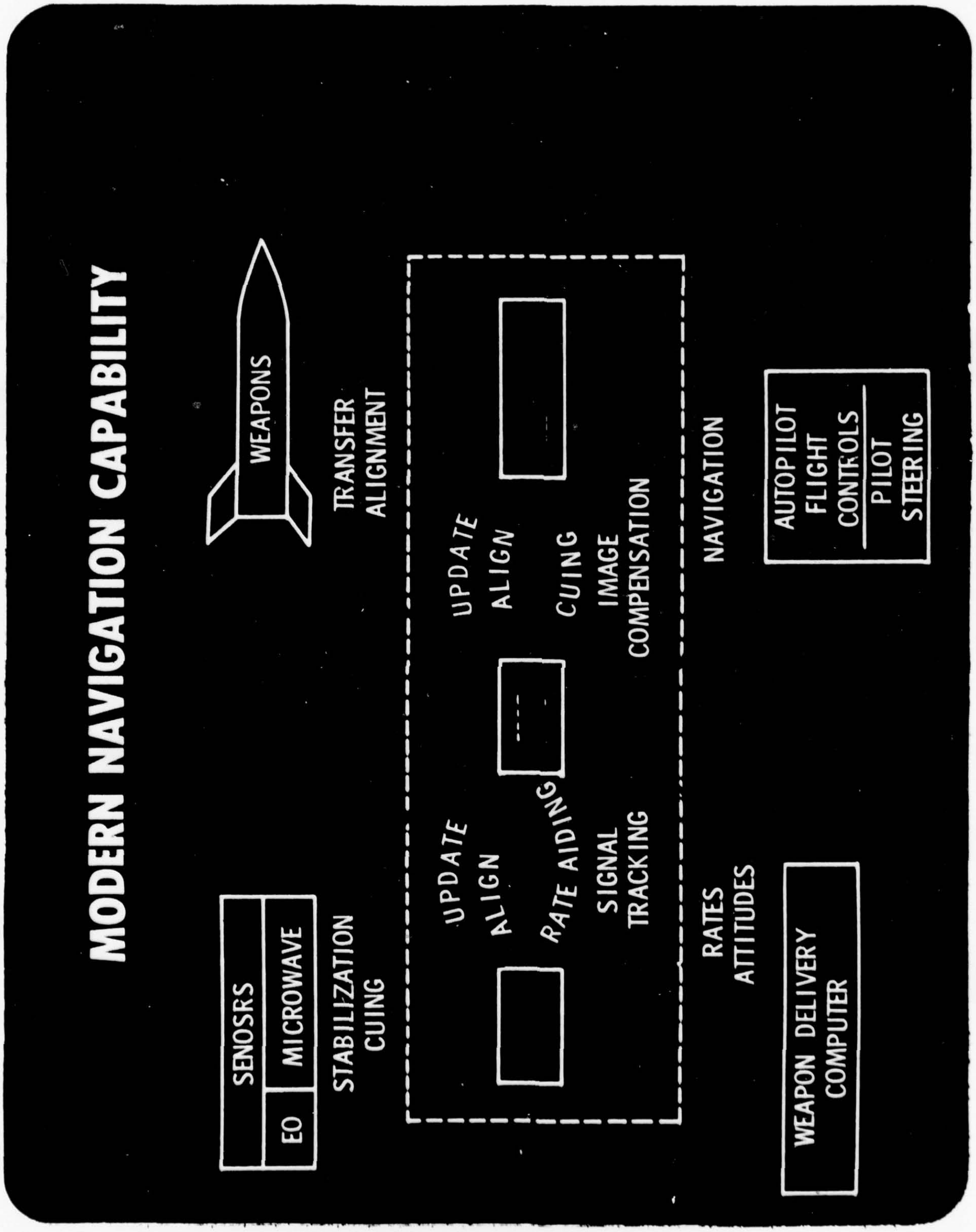
SINCE ALL FUTURE NAVIGATION SYSTEMS WILL BE INTEGRATED INTO THE AVIONICS SUITE, IT IS WORTH SPENDING A FEW MINUTES TO DISCUSS THE ARCHITECTURE OF THE AVIONICS SUITE.

# AVIONICS ARCHITECTURE

## MODERN NAVIGATION CAPABILITIES

THIS IS OUR VIEW OF THE NAVIGATION SUITE IN THE 1980's. THE THREE PRIME NAVIGATION SENSORS ARE GPS-INS-RADAR. THESE THREE SUBSYSTEMS ARE TIED TOGETHER IN SUCH A WAY THAT THE COMBINATION OF THE THREE SATISFY ALL OF THE NAVIGATION REQUIREMENTS PREVIOUSLY DISCUSSED. LETS TAKE A MINUTE TO REVIEW THE INTERACTION BETWEEN THE PRIME NAVIGATION SENSORS AND THEN DETERMINE HOW THEY INTERACT WITH THE REST OF THE AVIONICS SUITE. FIRST LETS LOOK AT THE GPS - INS. THE GPS PROVIDE EXTREMELY ACCURATE ALIGNMENT AND UPDATE INFORMATION TO THE INS. THE INS IN-TURN PROVIDES MOTION DATA TO THE GPS RECEIVER FOR INCREASED ANTI-JAM PERFORMANCE. IF FOR SOME REASON THE GPS CANNOT PROVIDE UPDATE INFORMATION, THE INS WILL CONTINUE TO NAVIGATE AND OBTAIN UPDATE/ POSITION FIX DATE FROM THE RADAR. THE RADAR WILL LIKEWISE GET MOTION COMPENSATION DATA FROM THE INS AND WILL FURTHER OBTAIN CUEING DATA FROM THE INS TO MINIMIZE RADIATING TIME DURING POSITION FIXING OR TARGET ACQUISITION. THE DEPENDENCE OF THESE THREE SYSTEMS IS CAUSING US TO EXAMINE THE OPTIONAL INTEGRATION OF THESE SYSTEMS AT SOME LENGTH. THE NAVIGATION SUITE THEN INTERACTS WITH THE REST OF THE AVIONICS SUITE IN THE FOLLOWING MANNER. THE NAVIGATION SUITE PROVIDES - TRANSFER ALIGNMENT TO WEAPONS - STABILIZATION AND CUEING FOR OUR EO AND MICROWAVE SENSORS - RATES AND ATTITUDES TO THE WEAPON DELIVERY COMPUTER AND NAVIGATION INFORMATION TO THE AUTOPILOT AND PILOT. THE NUMBER OF INTERFACES REQUIRED TO THE NAVIGATION SUITE ARE GOING TO REQUIRE A PRECISE WELL THOUGHT-OUT AVIONICS ARCHITECTURE.

PRINCIPLE POINT BEING - THE NEW NAVIGATION EQUIPMENTS WILL BE DESIGNED AND PROCURED TO INTERFACE WITH THIS STANDARD ARCHITECTURE.


MODERN NAVIGATION CAPABILITY
SENOSRS
EO
MICROWAVE
STABILIZATION
CUING
WEAPONS
TRANSFER
ALIGNMENT
UPDATE
ALIGN
RATE AIDING
SIGNAL
TRACKING
UPDATE
ALIGN
CUING
IMAGE
COMPENSATION
RATES
ATTITUDES
NAVIGATION
WEAPON DELIVERY
COMPUTER
AUTOPILOT
FLIGHT
CONTROLS
PILOT
STEERING

## ARCHITECTURAL EVOLUTION

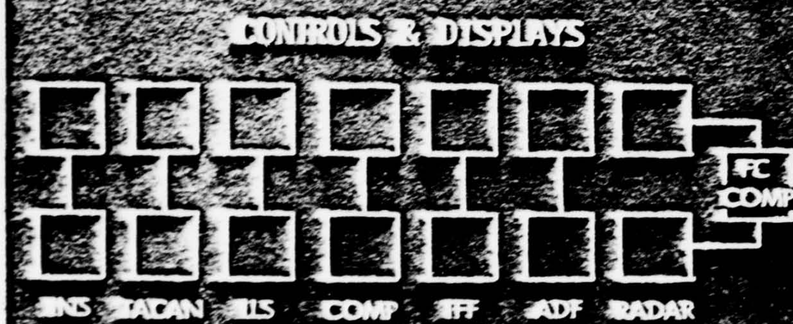
TODAYS AVIONICS ARCHITECTURE, OR TO BE MORE PRECISE, THE ARCHITECTURE OF THE PAST DECADE·IS CHARACTERIZED BY THE MOOD OF THE 1960 "I WANT TO DO IT MY WAY." THERE WAS LITTLE THOUGHT OR ATTENTION PAID TO THE USE OF COMMON EQUIPMENTS FOR SIMILIAR REQUIREMENT OR PROVISIONS MADE FOR THE ADDITION OF NEW EQUIPMENTS. THE AVIONICS SUITES GENERALLY CONSISTED OF SUBSYSTEMS WITH DEDICATED CONTROLS AND DISPLAYS. FEW SYSTEMS WERE INTEGRATED, THOSE THAT WERE INTEGRATED CONSISTED OF HARD WIRING, LIMITING THE GROWTH POTENTIAL OF THOSE SUBSYSTEMS. USING TODAYS YARDSTICK THE AVIONICS SUITES HAD RATHER LIMITED CAPABILITIES: 2NM POSITION ACCURACY - LIMITED JAM RESISTANT COMMUNICATIONS AND NAVIGATION EQUIPMENT - AND LIMITED TARGET IDENTIFICATION.

THE AVIONICS REQUIREMENTS OF THE 1980's WILL DEMAND THAT THE MAJORITY OF AVIONICS SUBSYSTEMS BE INTEGRATED TO PERFORM THE TASKS OF PRECISION ALL WEATHER STRIKE - BEYOND VISUAL RANGE IDENTIFICATION OF TARGETS - 10-30 METER POSITION ACCURACY AND - JAM RESISTANT COMMUNICATION AND NAVIGATION. IN ORDER TO ACCOMPLISH THESE GOALS IN A TIMELY AND COST EFFECTIVE MANNER, IT WILL REQUIRE THE DEFINITION OF A VERSATILE AVIONICS ARCHITECTURE WITH COMMON CORE EQUIPMENTS. WE ARE CURRENTLY DEFINING SUCH A SYSTEM IN THE DIGITAL AVIONICS INFORMATION SYSTEMS PROGRAM. THE

# ARCHITECTURAL EVOLUTION

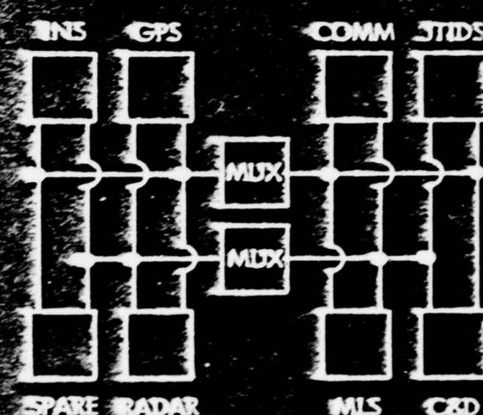
TODAY

- DEDICATED DISPLAYS
- LIMITED USE OF MULTIPLEX
- LIMITED GROWTH CAPABILITY
- DAY VFR STRIKE OPTIONS
- 2NM ACCURACY
- LIMITED JAM RESISTANT COM/NAV
- LIMITED TARGET ID




1980's (SOFTWARE CONTROLLED AVIONICS)

- COMMON CORE
- MULTI-PURPOSE CONTROLS & DISPLAYS
- ALL WEATHER STRIKE
- GROWTH CAPABILITY
- BVR ID
- 10-100M ACCURACY
- AJ COM/NAV



## MAJOR NAVIGATION PROGRAMS

ON THE NEXT FEW SLIDES I WILL DISCUSS SEVERAL NAVIGATION PROGRAMS WHICH ARE BEING DESIGNED TO FIT INTO THE ARCHITECTURE JUST DISCUSSED.

# MAJOR NAVIGATION PROGRAMS

## AVIONIC SYSTEMS

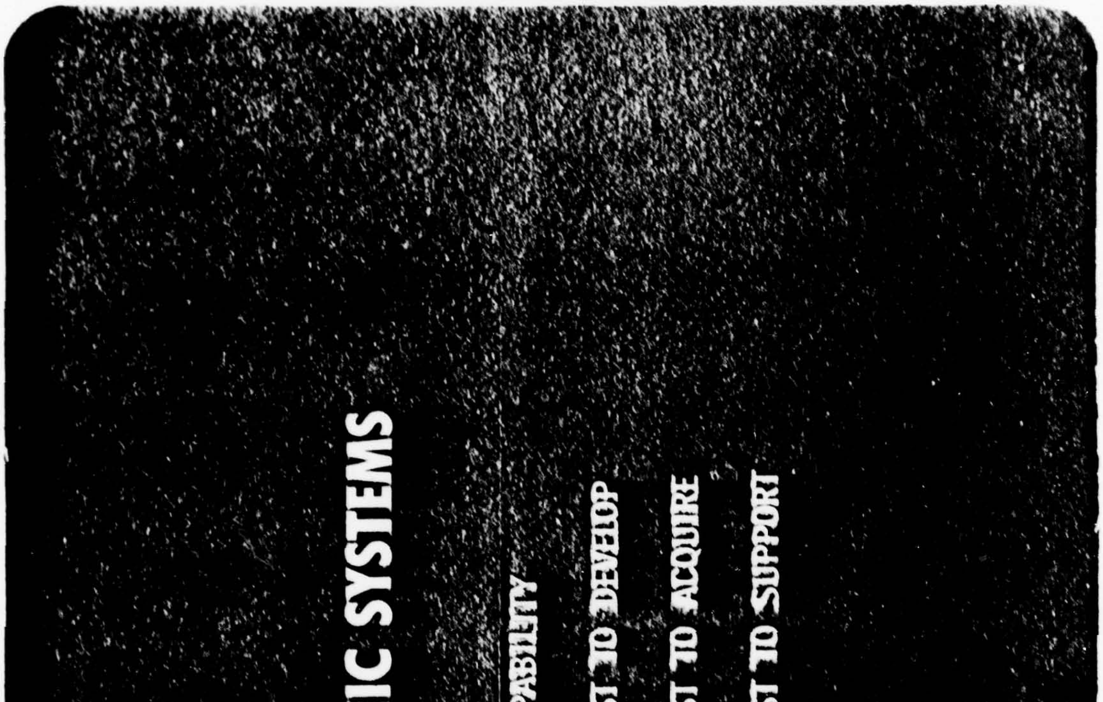
BEFORE I GET INTO A BRIEF DESCRIPTION OF SEVERAL NAVIGATION EFFORTS, I WOULD LIKE TO COVER AN AREA WHICH IS CENTRAL TO EACH OF THESE EFFORTS-" COST."

IN COMMON WITH THE OTHER SERVICES, THE MAJOR PROBLEM FACING THE AIR FORCE TODAY IS TO DEVELOP IMPROVED CAPABILITY WITHIN COST - COST TO DEVELOP - COST TO ACQUIRE AND COST TO SUPPORT. THE COST OF SYSTEMS ACQUISITION AND SUPPORT ARE RISING -- DRIVEN, AT LEAST PARTIALLY, BY ECONOMIC PRESURES BEYOND OUR CONTROL. THE OTHER ASPECT WHICH COMPOUNDS THE PROBLEM IS THE TREND TO REDUCE GOVERNMENTAL SPENDING. THE IMPACT BEING, WE WILL HAVE LESS MONEY TO DO FEWER PROGRAMS AND THESE EFFORTS MUST BE PROPERLY STRUCTURED AND MANAGED IF WE ARE TO SUCCEED WITH MODERNIZING THE FLEET.

WE ARE ATTACKING THE PROBLEM OF COSTS ON MANY FRONTS SIMULTANEOUSLY. AS YOU KNOW STANDARDIZATION IS A WAY TO CONTROL PROLIFERATION SO THAT YOU CAN AVOID REINVENTING NEW SOLUTIONS FOR EVERY NEW APPLICATION. WE CURRENTLY HAVE SEVERAL STANDARDIZATION EFFORTS IN THE NAVIGATION AREA - THE $F^3$ STANDARD INS, STANDARD DOPPLER, STANDARD TACAN AND GPS.

WE'RE ALSO ATTACKING AVIONICS COSTS THROUGH OTHER METHODS - TRYING TO MAXIMIZE COMPETITION THROUGHOUT DEVELOPMENT AND PRODUCTION - BUYING NEW EQUIPMENT UNDER RELIABILITY IMPROVEMENT WARRANTIES (RIW's) - IMPROVING OUR RELIABILITY TESTING THROUGH THE USE OF COMBINED ENVIRONMENTAL TESTS (CERT).

THE FOLLOWING PROGRAMS I WILL DISCUSS WILL USE THE PREVIOUS MENTIONED COST REDUCTION TECHNIQUES SINGLELY OR IN UNISON TO HOLD DOWN COST.


AVIONIC SYSTEMS
CAPABILITY
COST TO DEVELOP
COST TO ACQUIRE
COST TO SUPPORT

## STANDARD INERTIAL NAVIGATOR

THE STANDARD MEDIUM ACCURACY INERTIAL NAVIGATOR PROGRAM IS A PROGRAM WHICH IS DIRECTED TOWARD PROVIDING AN EXISTING CAPABILITY AT A LOWER COST. THIS STANDARDIZATION EFFORT IS BUILT ON THE FORM-FIT AND FUNCTION PHILOSOPHY. ALL THE EXTERNAL INTERFACES HAVE BEEN DEFINED-MECHANICAL, ELECTRICAL, ENVIRONMENTAL, AND SIGNAL, ALONG WITH THE WEIGHT AND SIZE. THE COMPONENTS INTERNAL TO THE BOX HAVE NOT BEEN STANDARDIZED TO ALLOW FOR TECHNOLOGY EVOLUTION. THE INERTIAL TECHNOLOGY IS EVOLVING SO RAPIDLY, IT WAS CONSIDERED UNDERSIRABLE TO PROCEED TO A PIECE PART STANDARDIZATION EFFORT AT THIS TIME.

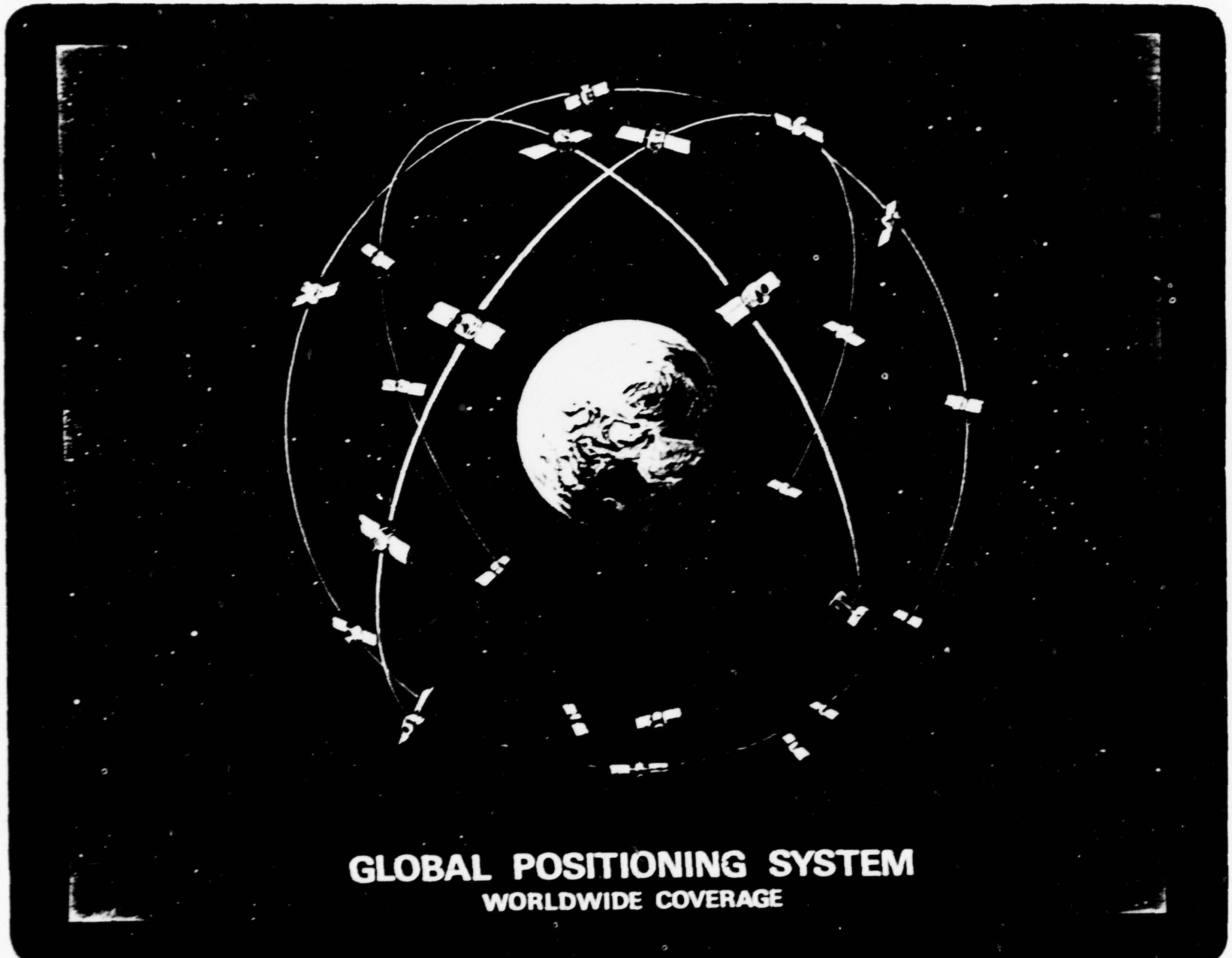
THE APPROACH TO REDUCE LIFE CYCLE COST INVOLVES THREE INTERACTING CONCEPTS. THE FIRST IS COMPETITION - THE VENDOR WILL BE AWARE THAT IF HIS SYSTEMS DOESN'T PERFORM SATISFACTORILY - THEY CAN BE ECONOMICALLY SWAPPED-OUT BECAUSE OF THE STANDARDIZATION APPROACH (I.E. INTERCHANGEABILITY), THEREBY HE IS INCENTIVISED TO PRODUCE QUALITY EQUIPMENT. SECONDLY IT INVOLVES KEEPING THE VENDOR INVOLVED WITH HIS EQUIPMENT AFTER DELIVERY. THIS COULD TAKE THE FORM OF MEAN TIME BETWEEN FAILURE GUARANTEES, RIWs, CONTRACT MAINTENANCE OR OTHER SUITABLE GUARANTEES. THE THIRD IS TO ASSURE A LARGE CONSISTANT MARKET FOR THE STANDARD WHICH THROUGH COMPETITION WILL REDUCE THE COST. THE ADDED BENEFIT OF INTERCHANGEABILITY BETWEEN VENDORS AND ACROSS AIRCRAFT COULD REDUCE THE REQUIREMENT FOR TEST EQUIPMENT, TECHNICAL ORDERS AND OTHER DATA. THE POTENTIAL SAVINGS TO BE ACCRUED FROM THIS EFFORT OVER THE NEXT TEN YEARS IS IN THE TEN'S OF MILLION DOLLARS.

THE INITIAL TARGET AIRCRAFT ARE THOSE PICTURED BELOW WITH THE INITIAL EMPHASIS BEING ON THE A-10.


STANDARD INERTIAL NAVIGATOR
FUNCTION
FIT
FORM
F
3
REDUCED LIFE CYCLE COSTS
COMPETITION
VENDOR INVOLVEMENT AFTER DELIVERY
MAINTAINABILITY
RELIABILITY
LARGE MARKET / INTERCHANGEABILITY

GPS WORLDWIDE COVERAGE

I AM SURE MOST OF YOU ARE FAMILIAR WITH THE GLOBAL POSITIONING SYSTEM PROGRAM. IT IS OF PARTICULAR INTEREST TO THE MILITARY AND THE AIR FORCE BECAUSE IT HAS THE ABILITY TO MEET VIRTUALLY ALL NAVIGATION REQUIREMENTS SAVE ONE - SELF CONTAINED. IT'S PROMISED 30 FEET POSITION ACCURACY FOR MOVING VEHICLES WILL UNDOUBTABLY REVOLUTIONIZE NAVIGATION AND HAVE A MAJOR IMPACT ON MILITARY SYSTEMS. THE PRIMARY EFFORT I WILL ADDRESS TODAY IS THE USER EQUIPMENT. IT IS THIS EQUIPMENT WHICH WILL BE INTEGRATED WITH THE INS AND RADAR TO PROVIDE OUR FUTURE NAVIGATION CAPABILITY.



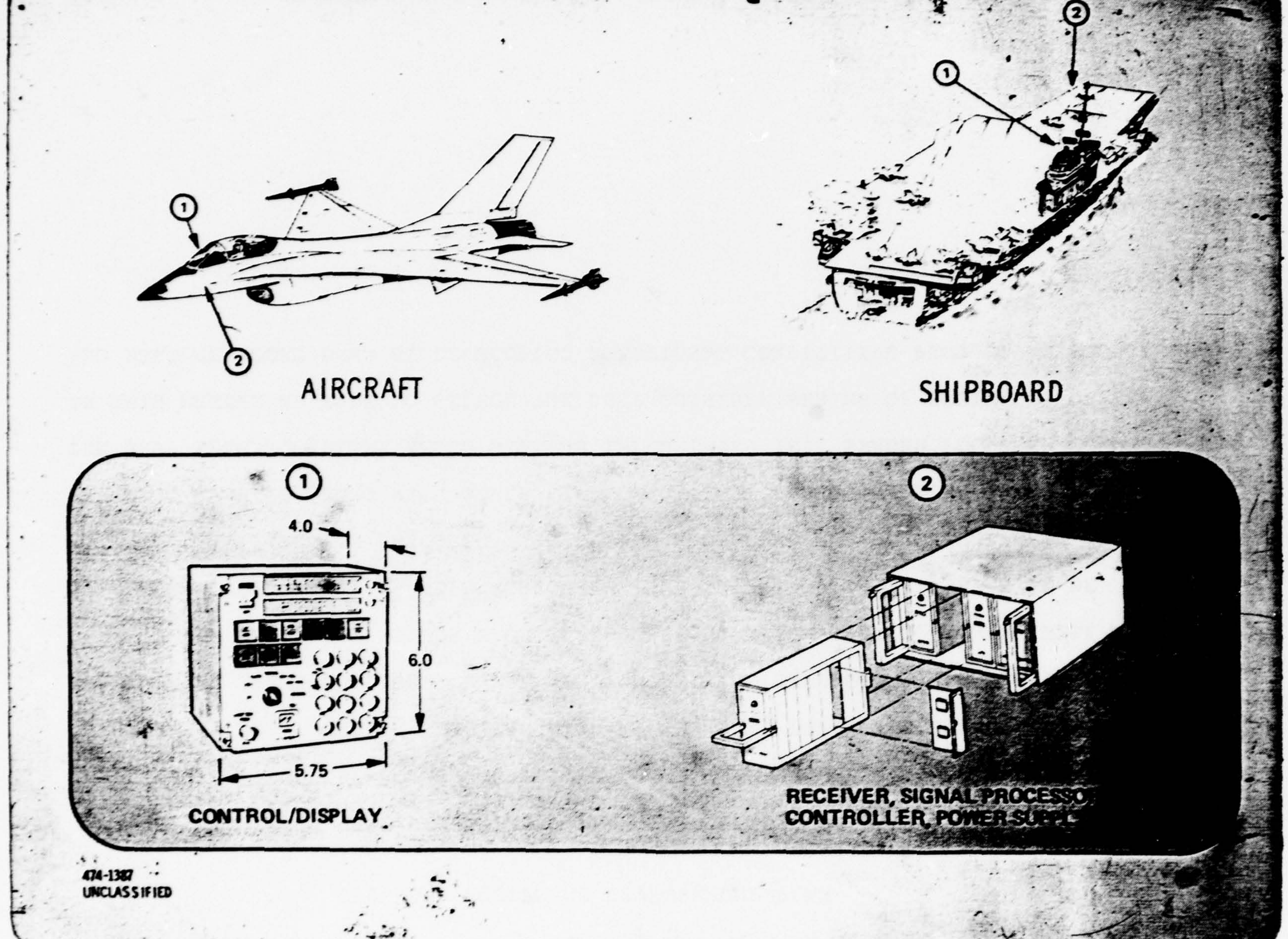

PRESENTATION

## GPS COMMONALITY OF EQUIPMENT

EARLY IN THE DEVELOPMENT OF THE USER EQUIPMENT, IT WAS DECIDED TO MAXIMIZE THE COMMONALITY BETWEEN USERS. THIS GOAL IS STILL PARAMOUNT. WE ARE TRYING TO MAXIMIZE THE MARKET FOR EACH TYPE OF USER EQUIPMENT OR SAYING IT ANOTHER WAY - TO MINIMIZE THE NUMBER OF DIFFERENT TYPES OF USER EQUIPMENTS. IN THIS PICTURE ARE DEPICTED AN AIRPLANE WITH A HIGH PERFORMANCE RECEIVER AND CONTROL AND DISPLAY USING THE IDENTICAL EQUIPMENT INSTALLED IN AN AIRCRAFT CARRIER.

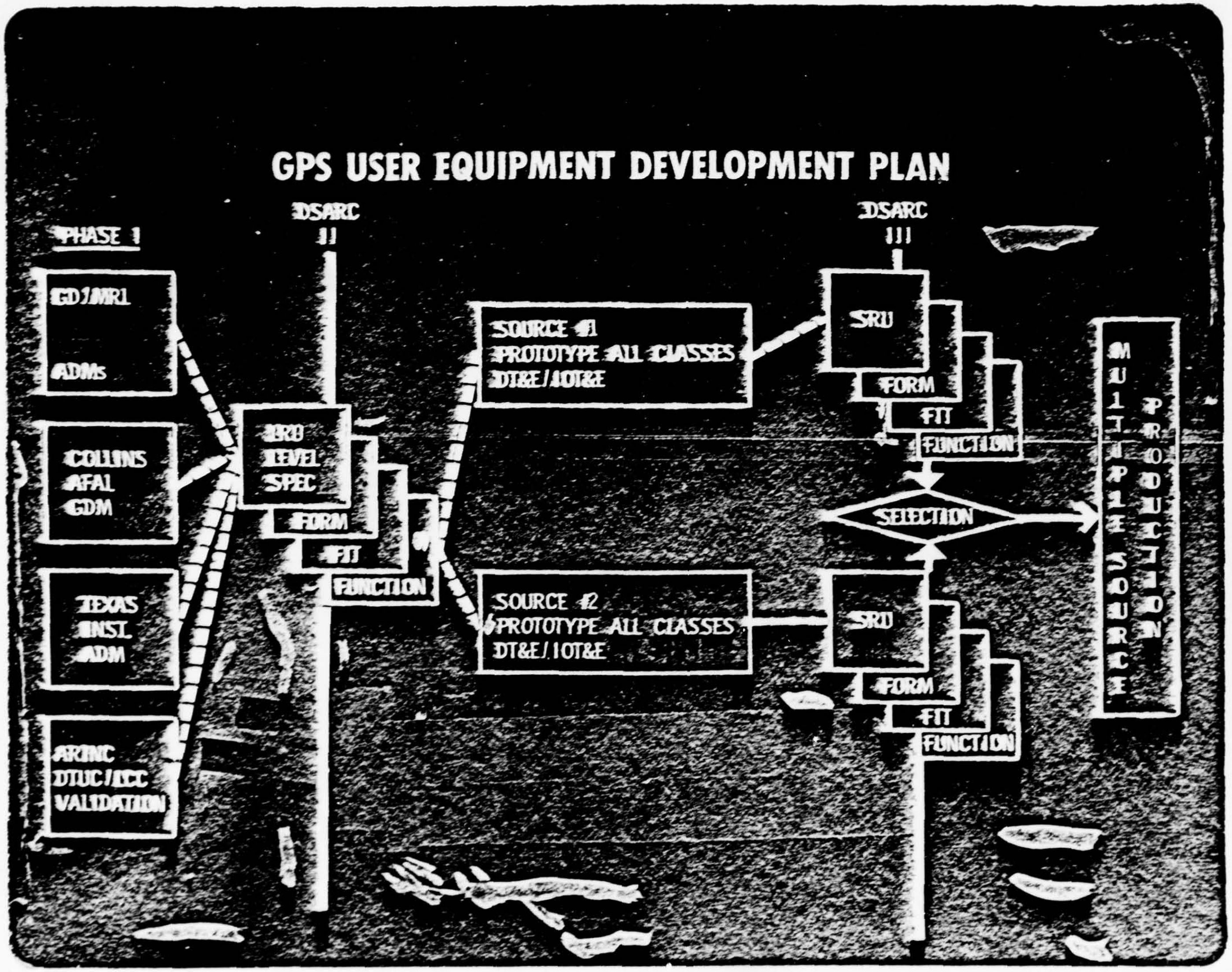
WE WANT TO REDUCE THE NUMBER OF USER EQUIPMENTS AND INCREASE THE COMMONALITY BETWEEN DIFFERENT TYPES OF USER EQUIPMENT. THIS IS AN ATTEMPT TO REDUCE THE OVERALL COST OF SYSTEMS BY INCREASING THE AVAILABLE MARKET SIZE THROUGH COMMONALITY/ STANDARDIZATION.

# COMMONALITY OF EQUIPMENT



## GPS USER EQUIPMENT DEVELOPMENT PLAN

THE USER EQUIPMENT DEVELOPMENT PLAN IS OUTLINED ON THIS CHART. AT THE COMPLETION OF THE DEVELOPMENT EFFORT CURRENTLY IN-PROGRESS WE WILL DEVELOP A SET OF FORM FIT AND FUNCTION SPECIFICATION AT THE LINE REPLACEABLE UNIT (LRU) LEVEL. USING THOSE SPECIFICATIONS WE PLAN TO COMPETE TWO DEVELOPMENT CONTRACTS FOR DEVELOPMENT OF RECEIVERS FOR EACH CLASS OF EQUIPMENT. THE EQUIPMENT WILL BE EVALUATED DURING DT&E AS WELL AS IOT&E. THE OUTPUT OF THIS PHASE WILL BE FORM FIT AND FUNCTION SPECIFICATION AT THE SRU LEVEL FOR EACH EQUIPMENT CLASS. THE TEST RESULTS ALONG WITH OTHER LIFE CYCLE COST FACTOR WILL BE USED TO SELECT THE BEST SPECIFICATIONS WHICH WILL BE IMPLEMENTED IN A LEADER FOLLOWER CONCEPT IN THIS MANNER WE HOPE TO SELECT THE BEST POSSIBLE SERIES OF EQUIPMENT DESIGNS AND HOLD THE COST DOWN BY DEVELOPING ADDITIONAL COMPETITIVE PRODUCTION SOURCES


GPS USER EQUIPMENT DEVELOPMENT PLAN
DSARC II
DSARC III
PHASE I
GD/MRL
ADMs
COLLINS
AFAL
GDM
TEXAS
INST.
ADM
ARINC
DTUC/LCC
VALIDATION
SRU
LEVEL
SPEC
FORM
FIT
FUNCTION
SOURCE #1
PROTOTYPE ALL CLASSES
DT&E/IOT&E
SOURCE #2
PROTOTYPE ALL CLASSES
DT&E/IOT&E
SRU
FORM
FIT
FUNCTION
SELECTION
MULTIPLE SOURCE
PRODUCTION

NAVIGATION EQUIPMENT

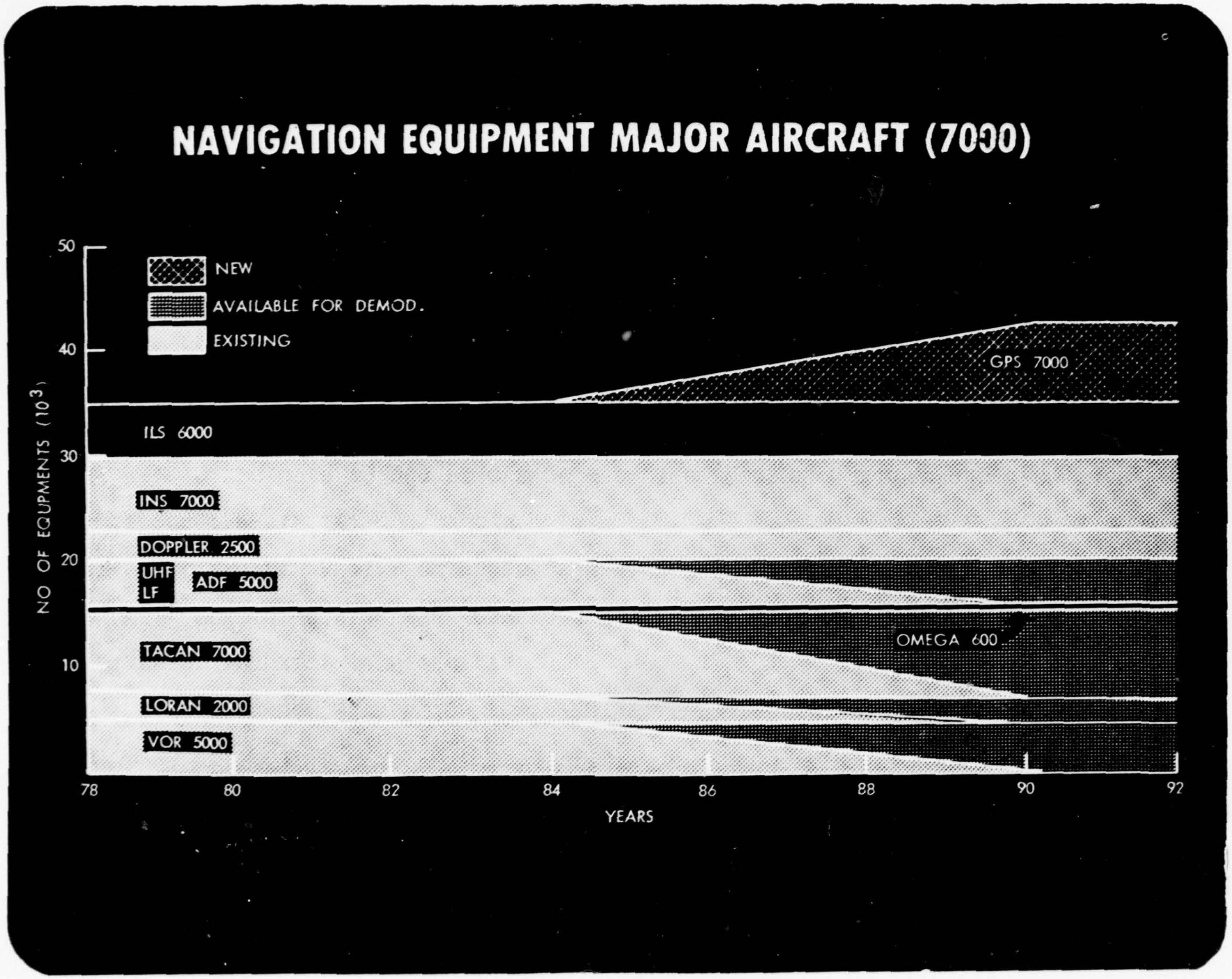
I WILL BRIEFLY REVIEW WITH YOU THE PROBABLE DISTRIBUTION OF NAVIGATION EQUIPMENTS OVER THE NEXT TEN TO FIFTEEN YEARS.

# NAVIGATION

# EQUIPMENTS

NAVIGATION EQUIPMENT MAJOR AIRCRAFT

WHAT WE HAVE PLOTTED HERE IS THE NUMBERS OF NAVIGATION EQUIPMENTS ON MAJOR AIRCRAFT. FOR THESE PURPOSES WE HAVE DEFINED A MAJOR AIRCRAFT AS HAVING MORE THAN 50 ACTIVE, AIRCRAFT IN A MISSION DESIGN SERIES IN 1980. THIS REPRESENTS APPROXIMATELY 7000 AIRCRAFT. THE TRENDS ESTABLISHED HERE WILL BE REPRESENTATIVES OF THE ENTIRE 10,000 AIRCRAFT FLEET. FIRST WE NOTE THAT THERE ARE APPROXIMATELY 35,000 PIECES OF NAVIGATION EQUIPMENT IN THIS SAMPLE. THE EQUIPMENTS CONSIST OF VOR, LORAN, TACAN, ADF, DOPPLER, INS AND ILS. SECONDLY WE SEE THE PROJECTED PHASE IN OF THE GPS USER EQUIPMENT OVER A SIX YEAR PERIOD. DURING THE SIX YEAR PHASE IN PERIOD WE HAVE IDENTIFIED APPROXIMATELY 20,000 PIECES OF NAVIGATION EQUIPMENT (IN RED) WHICH COULD BE PHASED OUT. IN OTHERWORDS, THE GPS USER EQUIPMENT WILL PROVIDE THE NAVIGATION FUNCTION PREVIOUSLY PERFORMED BY THAT EQUIPMENT. THE AIR FORCE HAS NOT COMMITTED TO THE PHASEOUT OF THAT EQUIPMENT UNTIL GPS IS VALIDATED AND A FULL REVIEW OF THE REDUNDANCY REQUIREMENTS HAS BEEN COMPLETED. THE NAVIGATION EQUIPMENT REMAINING IN THE LATE 80's IS BASICALLY OUR GPS, INS COMBINATION-WITH THE DOPPLER REQUIRED FOR CERTAIN STRATEGIC MISSIONS. THIS PLOT THEN GIVES US A VIEW OF THE TIME PHASING AND QUANITY OF NEW EQUIPMENT AND THE POTENTIAL PHASEOUT OF OLD EQUIPMENTS. THIS PLOT IS BASED ON POTENTIAL INSTALLATION DATES.


NAVIGATION EQUIPMENT MAJOR AIRCRAFT (7000)
NEW
AVAILABLE FOR DEMOD.
EXISTING
GPS 7000
ILS 6000
INS 7000
DOPPLER 2500
UHF
LF
ADF 5000
OMEGA 600
TACAN 7000
LORAN 2000
VOR 5000
NO OF EQUIPMENTS ($10^3$)
50
40
30
20
10
78
80
82
84
86
88
90
92
YEARS

## CONCLUSIONS

IN SUMMARY, I WOULD LIKE TO EMPHASIZE THE FOLLOWING SIX POINTS.

1. THE GPS - INS - RADAR WILL BE THE STANDARD NAVIGATION SUITE OF THE FUTURE.

2. THESE NEW NAVIGATION EQUIPMENT WILL BE REQUIRED TO INTERFACE THROUGH A STANDARD AVIONICS ARCHITECTURE.

3. COST OF EQUIPMENTS (DEVELOPMENT, ACQUISITION AND SUPPORT) IS A MAJOR AIR FORCE PROBLEM ANDIF NOT PROPERLY MANAGED/CONTROLLED, IT COULD EVENTUALLY LIMIT OUR CAPABILITY.

4. SINCE OVER 20,000 PIECES OF GPS USER EQUIPMENT CAN BE PROCURED OVER THE NEXT 12 YEARS - WE MUST ASSURE OURSELVES WE HAVE A SOUND STANDARDIZATION POLICY WHICH WILL MINIMIZE THE LIFE CYCLE COST OF THIS EQUIPMENT.

# CONCLUSIONS

1. GPS - INS - RADAR - STANDARD NAVIGATION SUITE
2. STANDARD ACHITECTURE
3. COST VERSUS IMPROVED CAPABILITY
4. GPS INTRODUCTION - PHASE OUT OF 20,000 PIECE OF NAVIGATION EQUIPMENT?
5. OVER 20,000 GPS USER EQUIPMENT SET TO BE PROCURED OVER THE NEXT 12 YEARS

BRIEFING TITLE

MANAGEMENT METHODS FOR INERTIAL SYSTEMS

JACK WUERTH
ELECTRONIC SYSTEMS GROUP, AUTONETICS DIVISION
ROCKWELL INTERNATIONAL

# MANAGEMENT METHODS
# FOR
# INERTIAL SYSTEMS

TO BE PRESENTED AT

ELEVENTH DATA EXCHANGE FOR INERTIAL SYSTEMS

DENISON UNIVERSITY
GRANVILLE, OHIO
28 OCTOBER 1977

BY

J. M. WUERTH

AUTONETICS STRATEGIC SYSTEMS DIVISION
ROCKWELL INTERNATIONAL

## BACKGROUND — AEROSPACE GUIDANCE AND METROLOGY CENTER ROLE

AEROSPACE GUIDANCE AND METROLOGY CENTER (AGMC)

- HAS REPAIRED INERTIAL EQUIPMENT
  - FOR 14 YEARS
  - SUPPORTING VARIOUS ITEM MANAGERS
- OBSERVES WIDE DIFFERENCES IN:
  - LOGISTICS REQUIREMENTS OF DIFFERENT SYSTEMS
  - MANAGEMENT APPROACH TO SYSTEM DEVELOPMENT AND PROCUREMENT
- HAS FUNDED ROCKWELL INTERNATIONAL TO:
  - COMPARE MANAGEMENT METHODS FROM DIFFERENT PROGRAMS
  - SUGGEST IMPROVEMENTS BASED ON LESSONS LEARNED

## BACKGROUND — ROCKWELL INTERNATIONAL ROLE

THE AUTONETICS GROUP OF ROCKWELL INTERNATIONAL (RI)

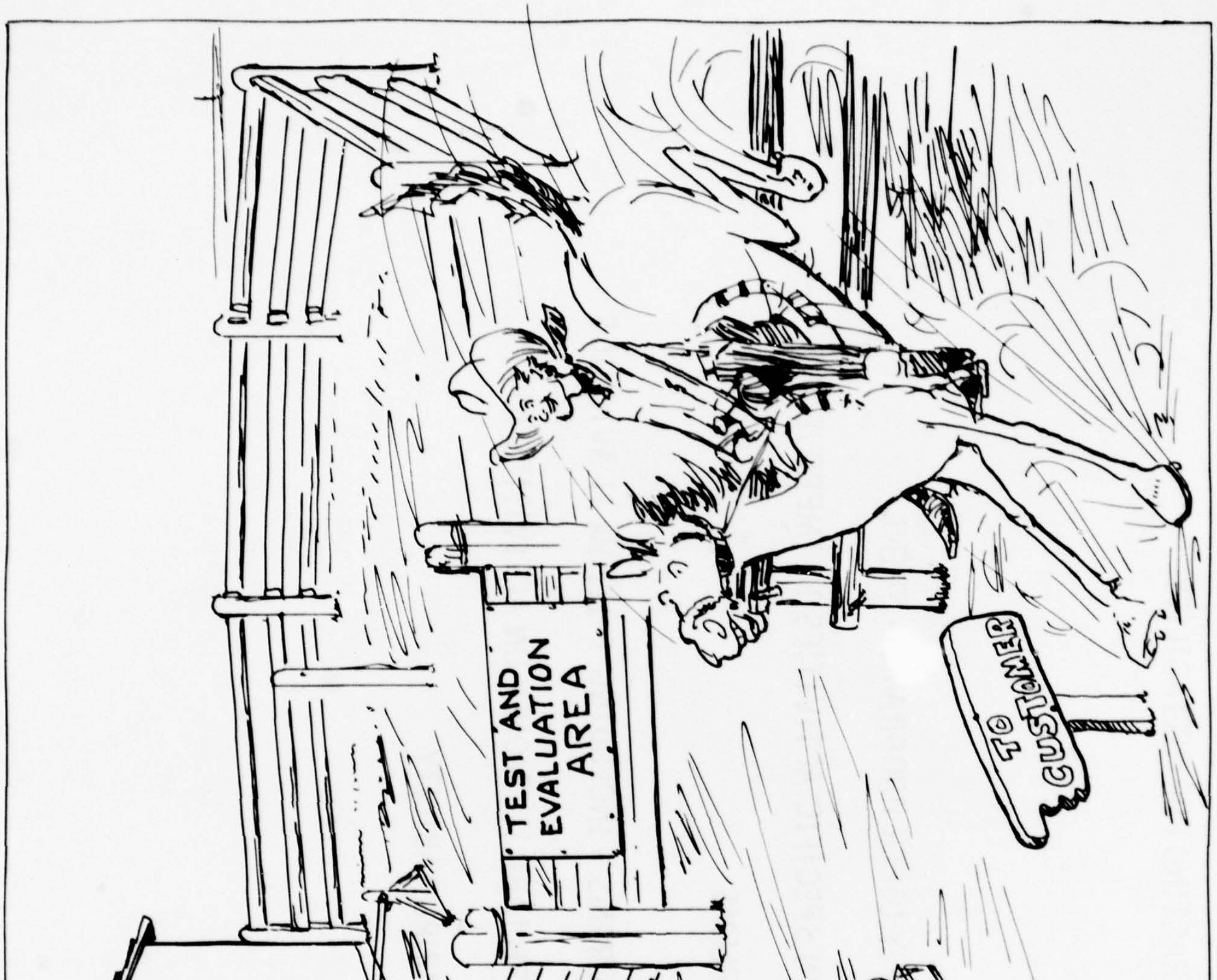
- HAS DEVELOPED AND PRODUCED INERTIAL EQUIPMENT
  - FOR 3 DECADES
  - FOR A WIDE RANGE OF CUSTOMERS
  - UNDER VARIOUS CONTRACT RELATIONSHIPS
- CONTRIBUTES TO THE AGMC REPAIR LOAD
  - 2651 MINUTEMAN BALLISTIC MISSILE GUIDANCE SYSTEMS
  - 322 FB-111A AND F111D AVIONICS SYSTEM - IRU'S
  - 101 MINIATURE SHIPS INERTIAL NAVIGATION SYSTEMS (MINISINS)

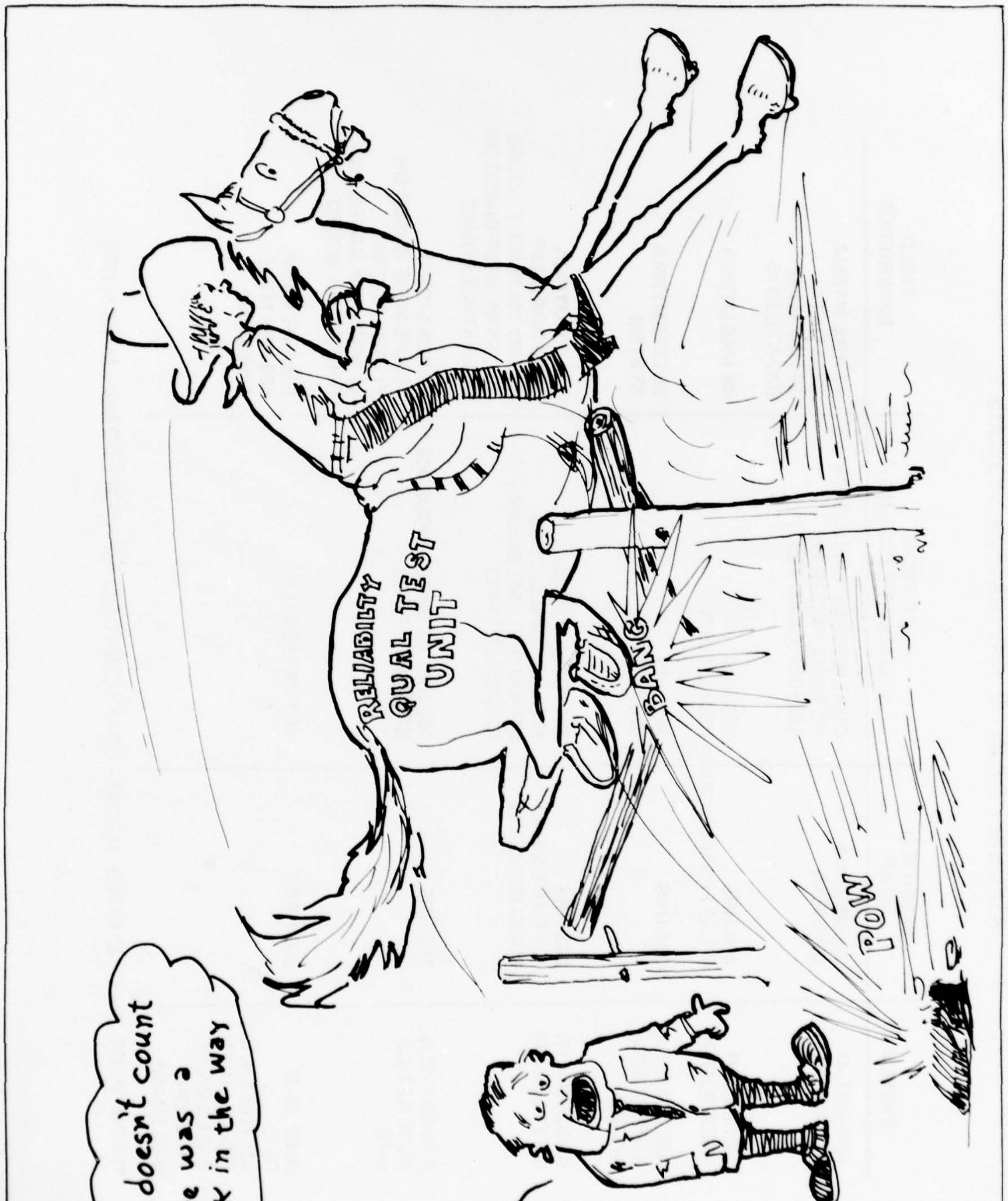
## PROJECT METHOD

- COLLECT AND REVIEW DATA
  - GOVERNMENT PUBLICATIONS
  - RAND STUDIES
  - AUTONETICS REPORTS
- INTERVIEW KEY PLAYERS IN ACQUISITION MANAGEMENT
  - GOVERNMENT SPO PERSONNEL
  - AUTONETICS' MANAGERS AND EXECUTIVES
- SUMMARIZE MANAGEMENT TECHNIQUE COMPARISONS
  - CONTRACTING METHODS
  - PROGRAM MANAGEMENT METHODS
- ATTEMPT TO CORRELATE
  - SYSTEM PERFORMANCE WITH MANAGEMENT TECHNIQUES
- PROVIDE RECOMMENDATIONS FOR IMPROVEMENT

## CONTRACTING FOR RELIABILITY

- MINUTEMAN - AND MANY OTHER PROGRAMS - SPENT RELIABILITY MONEY ON SPECIFIC ACTIVITIES TO IMPROVE AND FIX RELIABILITY PROBLEMS
- MANY AVIONICS PROGRAMS - INCLUDING F-111 Mk II AVIONICS SUBCONTRACT SPENT RELIABILITY MONEY ON ACTIVITIES TO FIX RESPONSIBILITY FOR UNRELIABILITY


TEST AND
EVALUATION
AREA
TO
CUSTOMER
HORSE
FEED


This doesn't count
There was a
Rock in the way
RELIABILITY
QUAL TEST
UNIT
BANG
POW

## RELIABILITY ASPECTS OF SOME AIR FORCE AIRCRAFT INERTIAL NAVIGATION SYSTEMS*

| SYSTEM | SPECIFIED MTBF | MTBF FROM RELIABILITY TESTING | FIELD EXPERIENCE |
|---|---|---|---|
| ASN-63(F-4) LITTON LN-12 | 200-250 HRS (SYSTEM) | QUALIFIED BY SIMILARITY TO NAVY PROGRAM – 125 HRS (QUAL TEST) | 42 HRS MTBMA (66-1 DATA) 30 HRS MTBF (DO-41 DATA) |
| ASN-90(A-7) SINGER KT-70 | 450 HRS (PLATFORM ONLY) | 225 HRS (QUAL TEST) | 48 HRS MTBMA |
| ASN-103(C-5A) NORTRONICS NIS-105 | 380 HRS | 541 HRS (QUAL TEST) | 35 HRS MTBMA SYSTEM |
| ASQ-20(F-111) LITTON LN-14 | 243 HRS (OFF THE SHELF PROCUREMENT) | 381 HRS (IRU/NDU) 1365 HRS (BALLISTICS COMPUTER) 164 90% CONF (CHAMBER TEST) | 20 HRS MTBMA 20-26 HRS MTBF BASED ON FLIGHT HOURS 30-39 HRS MTBF BASED ON OPERATING HOURS |
| AJN-16(F-111) AUTONETICS N-16 | 350 HRS | 360 HRS AT 80% CONFIDENCE (CHAMBER TEST) | 26 HRS MTBMA 26 HRS MTBF BASED ON FLIGHT HOURS 47 HRS MTBF BASED ON OPERATING HOURS |
| AN/AJN-17 (B-1) LITTON LN-15S (DATA GIVEN BASED ON LN-15 OR B-52 SRAM) | 650 HRS | NOT PRESENTED | 276 HRS MTBR 583 HRS MTBF FOR SRAM |

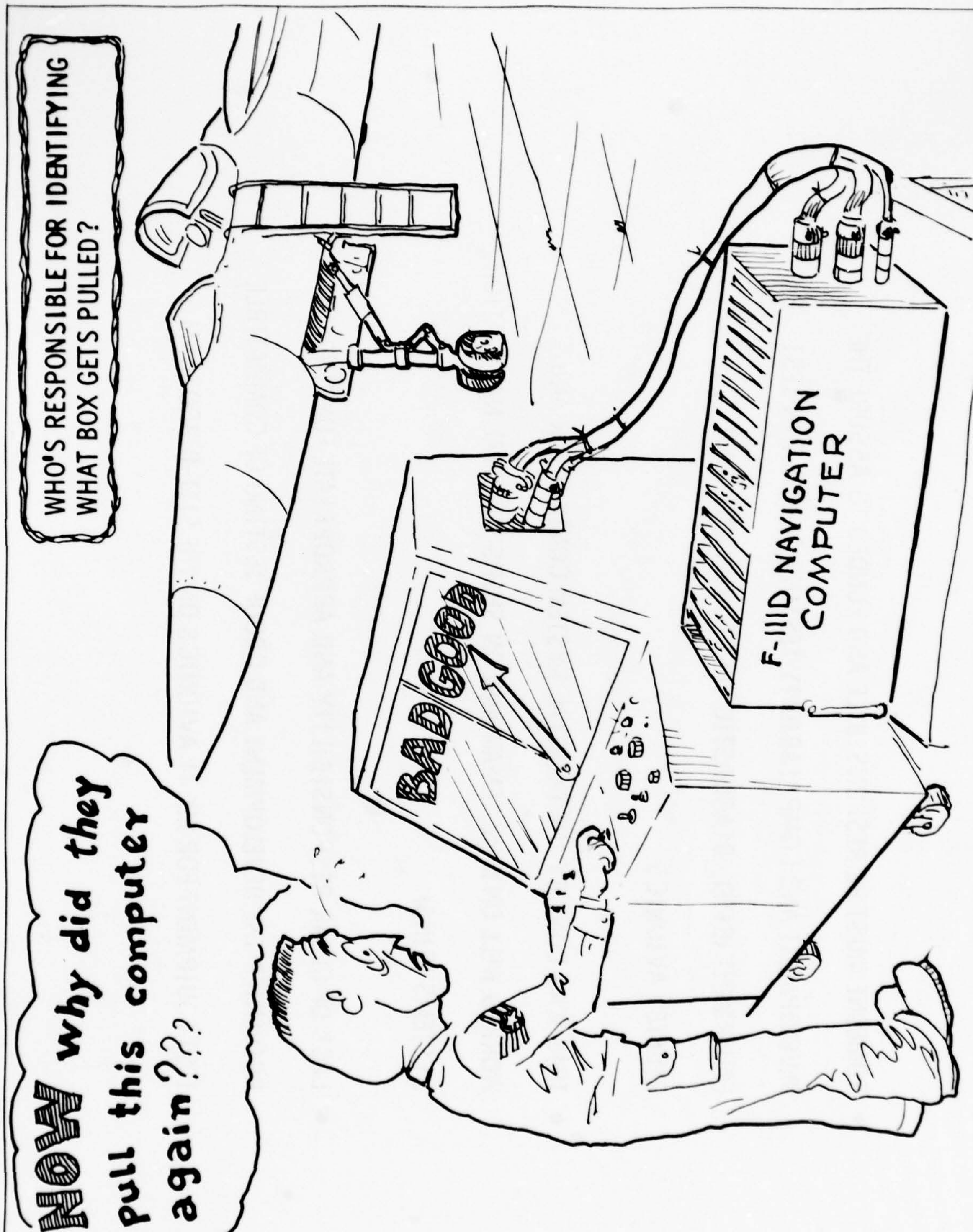
*FROM-PAGE 20- G&C PANEL REPORT- USAF SCIENTIFIC ADVISORY BOARD- MARCH 1975

## THE NEED FOR AVIONICS SYSTEM INTEGRATION

- SOMEONE MUST BE RESPONSIBILE AND FUNDED TO ASSURE THE DEVELOPMENT AND COMPATABILITY TESTING OF BUILT IN TEST EQUIPMENT (BITE), DIAGNOSTIC TEST EQUIPMENT, AND RELATED AVIONICS

- THIS WAS DONE BY THE INERTIAL SYSTEM CONTRACTOR AND WORKED WELL ON MINUTEMAN AND ON SHIPS INERTIAL NAVIGATION SYSTEMS (SINS)

- LACK OF CLEAR RESPONSIBILITY AND APPROPRIATE FUNDING PREVENTED THE DEVELOPMENT AND PROOF TESTING OF COMPATIBLE TEST EQUIPMENT FOR MK II AVIONICS ON THE F111-D PROGRAM


WHO'S RESPONSIBLE FOR IDENTIFYING WHAT BOX GETS PULLED?
NOW why did they pull this computer again???
BAD GOOD
F-111D NAVIGATION COMPUTER

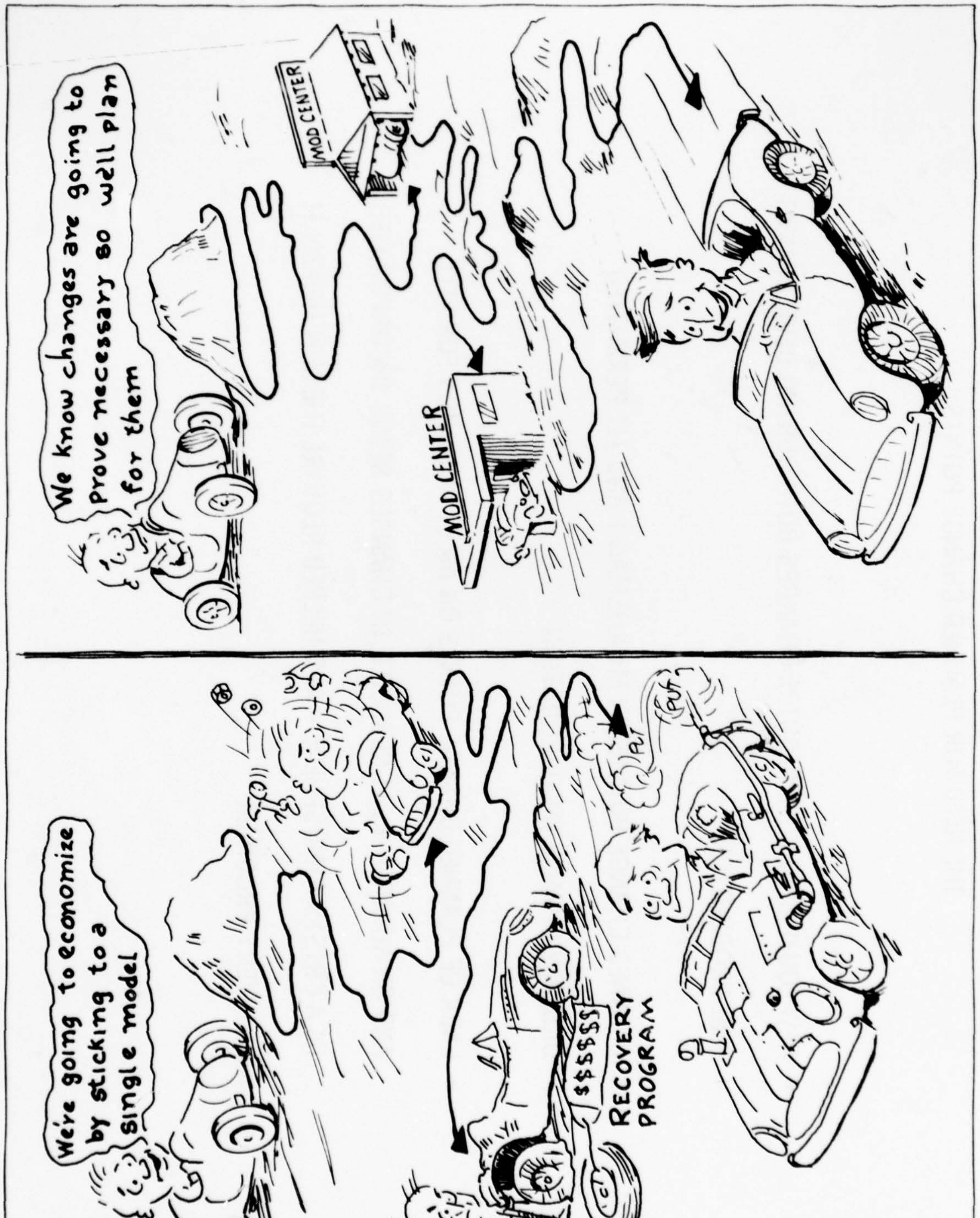
## THE NEED FOR PLANNED CHANGE POINTS

- NEW EQUIPMENT WILL REQUIRE CHANGES BOTH DURING DEVELOPMENT AND PRODUCTION
- PLANNED CHANGE POINTS ON MINUTEMAN I AND III PERMITTED ORDERLY CHANGE INCORPORATION
- LACK OF PLANNED CHANGE POINTS ON Mk II AVIONICS FOR F111 AND ON MINUTEMAN II RESULTED IN CHANGES BEING INCORPORATED IN A CRISIS ATMOSPHERE - AND HELPED REQUIRE THE MINUTEMAN II RECOVERY PROGRAM

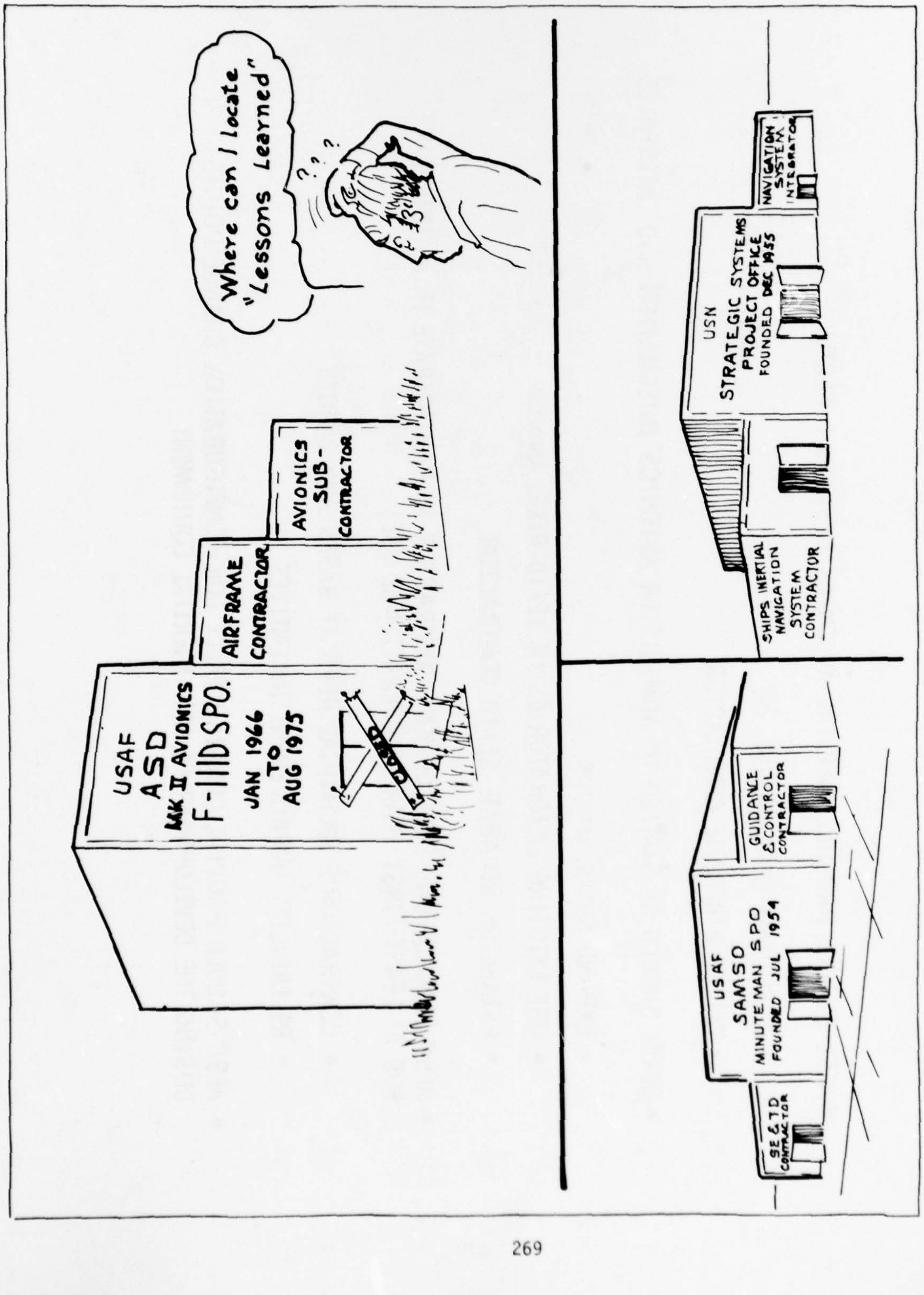




NO OF EQUIPMENTS ($10^3$)



We're going to economize by sticking to a single model
$$$$$
RECOVERY PROGRAM
We know changes are going to prove necessary so well plan for them
MOD CENTER
MOD CENTER


USAF
ASD
MK II AVIONICS
F-111D SPO.
JAN 1966
TO
AUG 1975
AIRFRAME CONTRACTOR
AVIONICS SUB-CONTRACTOR
Where can I locate "Lessons Learned"
? ? ?
SE&TD CONTRACTOR
USAF
SAMSO
MINUTEMAN SPO
FOUNDED JUL 1954
GUIDANCE & CONTROL CONTRACTOR
SHIPS INERTIAL NAVIGATION SYSTEM CONTRACTOR
USN
STRATEGIC SYSTEMS
PROJECT OFFICE
FOUNDED DEC 1955
NAVIGATION SYSTEM INTEGRATOR

## RECOMMENDATIONS CONCERNING CONTRACTING

- AFSC SHOULD PROCURE INERTIAL AVIONICS SYSTEMS DIRECTLY
  - ASSOCIATE CONTRACTOR, OR
  - GFE TO AIRFRAME CONTRACTOR
- SPO's SHOULD BE STAFFED TO ADMINISTER AVIONICS INTEGRATION AND INTERFACES
  - EXPAND SPO's, AND/OR
  - USE EXISTING LABORATORIES IN SE/TD ROLE, AND/OR
  - ESTABLISH SEPARATE SE/TD CONTRACTOR
- AFSC SHOULD FUND DEVELOPMENT CONTRACTOR TO PARTICIPATE IN MAINTENANCE FOR AT LEAST FIRST YEAR OF OPERATIONAL USE
  - CONTRACTOR'S TECHNICAL REPS AT BASES AND DEPOTS
  - RELIABILITY IMPROVEMENT INCENTIVES
- AFSC SHOULD PROVIDE CONTRACTUALLY FOR CONFIGURATION CHANGE POINTS DURING THE DEVELOPMENT OF NEW INERTIAL EQUIPMENT

SYSTEM COMPARISON REQUIRES SYSTEM UNDERSTANDING

- "FAILURE RATE" DIFFERENCES MAY BE MISLEADING
  - SYSTEM ENVIRONMENTS DIFFER
  - FAULTY NAVIGATION AIDS CAN CAUSE ERRONEOUS IRU FAILURE INDICATION
  - MANY "FAILURE RATE" DEFINITIONS ARE USED
  - MAINTENANCE CONCEPTS ARE DIFFERENT

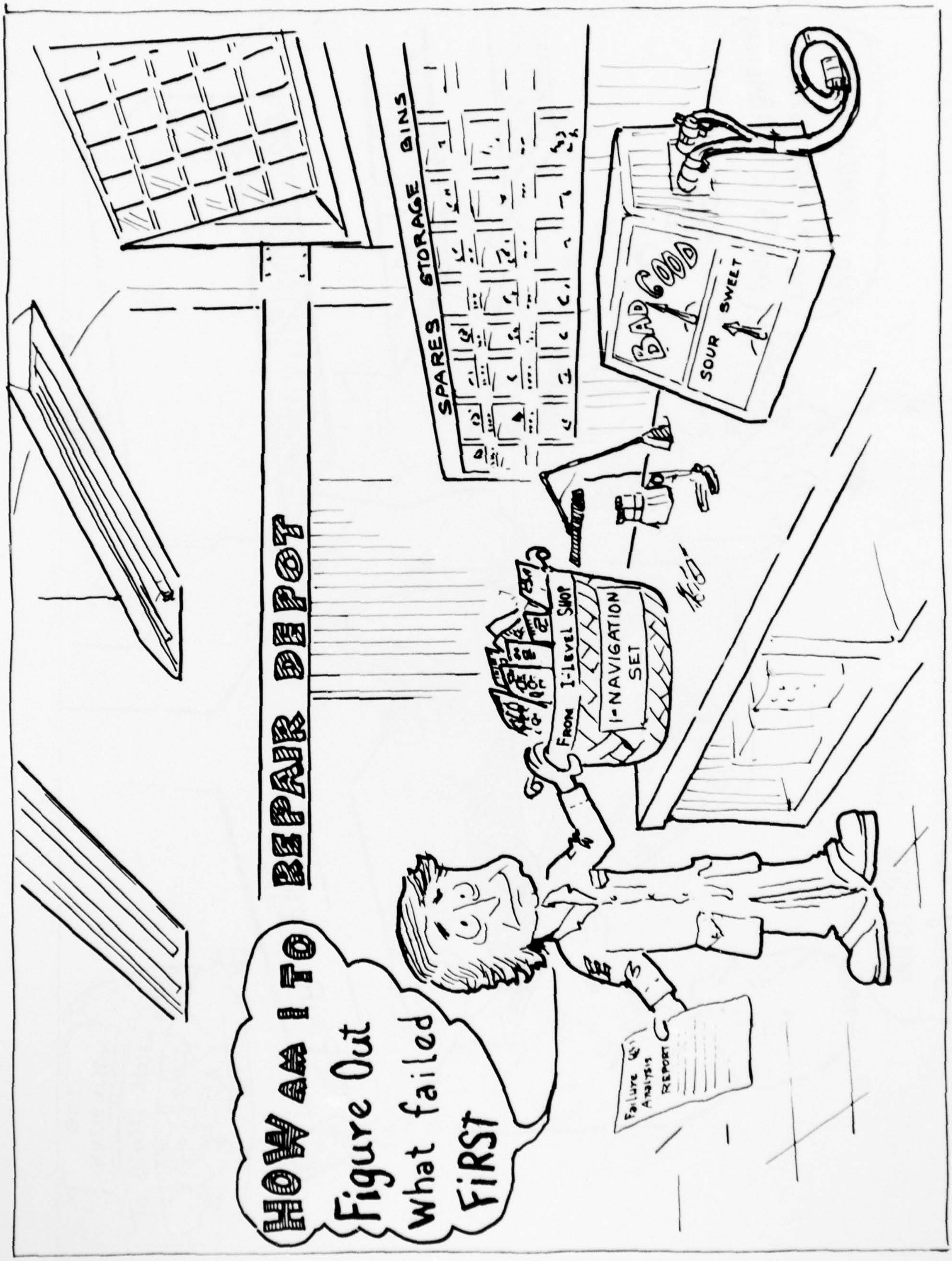

THIS Comparison doesn't have a real MEANING
AIRCRAFT SYSTEM MTBF
MISSILE SYSTEM MTBF
SOUR ↔ SWEET


ANNUAL SUPPORT COST PER INSTALLATION
Lets use this measurement that allows a meaningful Comparson
COST OF DEPOT REPAIRS (SYSTEMS)
COST OF FIELD REPAIRS
COST OF DEPOT REPAIR (INSTRUMENTS)
COST OF DEPOT REPAIR (MODULES)
ASCPI SCALE
MFD by USAF

## THE ROLE OF INTERMEDIATE (I-LEVEL) MAINTENANCE

- THE NEED TO KEEP AIRCRAFT IN FLYING CONDITION IS PRIME!
- GENERATING VALID FAILURE DATA ON WHICH TO RECOMMEND IMPROVEMENTS IS DIFFICULT WITH MANY LEVELS OF MAINTENANCE
- STUDIES ARE BEING CONDUCTED, AND SHOULD BE CONTINUED CONCERNING THE NEED AND COST OF I-LEVEL MAINTENANCE


Keep those AIRCRAFT FLYING MEN
? ? ?
YEA I KNOW, IF YOU DON'T HAVE SPARE PARTS CANABALIZE
BAD GOOD
REPAIR BENCH
TO DEPOT WHEN FULL
I NAVIGATION SET
SPARE COMP


HOW AM I TO Figure Out what failed FIRST
REPAIR DEPOT
SPARES STORAGE BINS
BAD GOOD
SOUR SWEET
FROM I-LEVEL SHOP
I-NAVIGATION SET
Failure Analysis REPORT

## THE NEED FOR GOOD COMMUNICATIONS

- RELIABILITY IMPROVEMENT PROGRAMS AFTER INITIAL DELIVERY
  - HAVE BEEN CONTINUALLY RECOMMENDED BY SURVEY TEAMS
  - REQUIRE GOOD FAILURE RECORDS
  - REQUIRE CUSTOMER INITIATIVE AND MONEY
  - REQUIRE CLOSE COMMUNICATIONS BETWEEN USER, DEPOT AND CONTRACTOR
- SEVERAL INERTIAL SYSTEM PROGRAMS WITH GOOD COMMUNICATIONS AND DATA SYSTEMS HAVE DEMONSTRATED SIGNIFICANT RELIABILITY GROWTH
- MOST AIRCRAFT INERTIAL SYSTEMS DEVELOPED ON SUB-CONTRACT TO AIRFRAME CONTRACTORS HAVE NOT SHOWN SIGNIFICANT RELIABILITY GROWTH

## INERTIAL SYSTEMS WITH RELIABILITY GROWTH

| END OF YEAR | SINS MOD 3 (MTBF, HOURS) | CAINS IMU (MTBF, HOURS) | MINUTEMAN III (MULTIPLES OF GOAL MTBF) |
|---|---|---|---|
| 1966 | 436 | | |
| 1967 | 397 | | |
| 1968 | 479 | | |
| 1969 | 663 | | |
| 1970 | 601 | 100 | 1.89 |
| 1971 | 896 | 201 | 2.15 |
| 1972 | 816 | 225 | 2.19 |
| 1973 | 807 | 200 | 2.38 |
| 1974 | 882 | 300 | 2.88 |
| 1975 | 1006 | 450 | 2.82 |
| 1976 | 1032 | 570 | 4.39 |

## EXCERPTS FROM - COMPENDIUM OF INERTIAL SYSTEMS
## REVISED 3 DECEMBER 1974 BY AFLC/MMAEA-WRIGHT-PATTERSON AFB

| PLATFORM TERMINOLOGY | MANUFACTURER | USAGE | MTBF |
|---|---|---|---|
| LN15S INERTIAL MEASUREMENT UNIT | LITTON | B52G/H; B-1 | 383 |
| LTN-51 INERTIAL MEASUREMENT UNIT | LITTON | T-43; VC-137 | 363 |
| LN-14 STABILIZED PLATFORM | LITTON | F111A/E | 196 |
| FLIP INERTIAL MEASUREMENT SET | NORTRONICS | C-5A; WC130B/E | 150 |
| LN16A-STELLAR INERTIAL REFERENCE UNIT | LITTON | PC135D/M/S; PC-130E | 138 |
| LN12 A/B/C | LITTON | F4C; RF4C; F4D/E | 122 |
| LN30M INERTIAL NAVIGATION MEASUREMENT UNIT | LITTON | F/TF-15 | 106 |
| KT-73 INERTIAL MEASUREMENT UNIT | KEARFOTT | A7D; AC130M | 98 |
| N-16 INERTIAL REFERENCE UNIT | AUTONETICS | F111 D/G; FB111 | 69 |
| CAVRS/KT71 INERTIAL MEASUREMENT UNIT | KEARFOTT | F105D | 62 |

## RECOMMENDATIONS CONCERNING DATA COMMUNICATIONS

- AN INDEPENDENT INERTIAL EQUIPMENT ENGINEERING SPECIALIST GROUP SHOULD BE ESTABLISHED
  - FUNDED BY AIR FORCE ACQUISITION LOGISTICS DIVISION
  - STAFFED BY TECHNICALLY QUALIFIED CIVILIAN AND AIR FORCE PERSONNEL
- THIS GROUP SHOULD
  - ESTABLISH TYPE AND FORM OF FAILURE AND REPORT DATA REQUIRED TO SUPPORT IMPROVEMENT RECOMMENDATIONS PERTAINING TO INERTIAL OR ASSOCIATED EQUIPMENTS
  - INTERACT WITH OTHER AIR FORCE ORGANIZATIONS AND CONTRACTORS IN ESTABLISHING SPECIAL TEST PROGRAMS REQUIRED TO OBTAIN DATA FOR PROBLEM SOLVING OR PRODUCT IMPROVEMENT RECOMMENDATIONS
  - COLLECT, MAINTAIN, EVALUATE AND PUBLISH APPROPRIATE DATA
  - RECOMMEND APPROPRIATE ACTION TO RESPONSIBLE AGENCIES

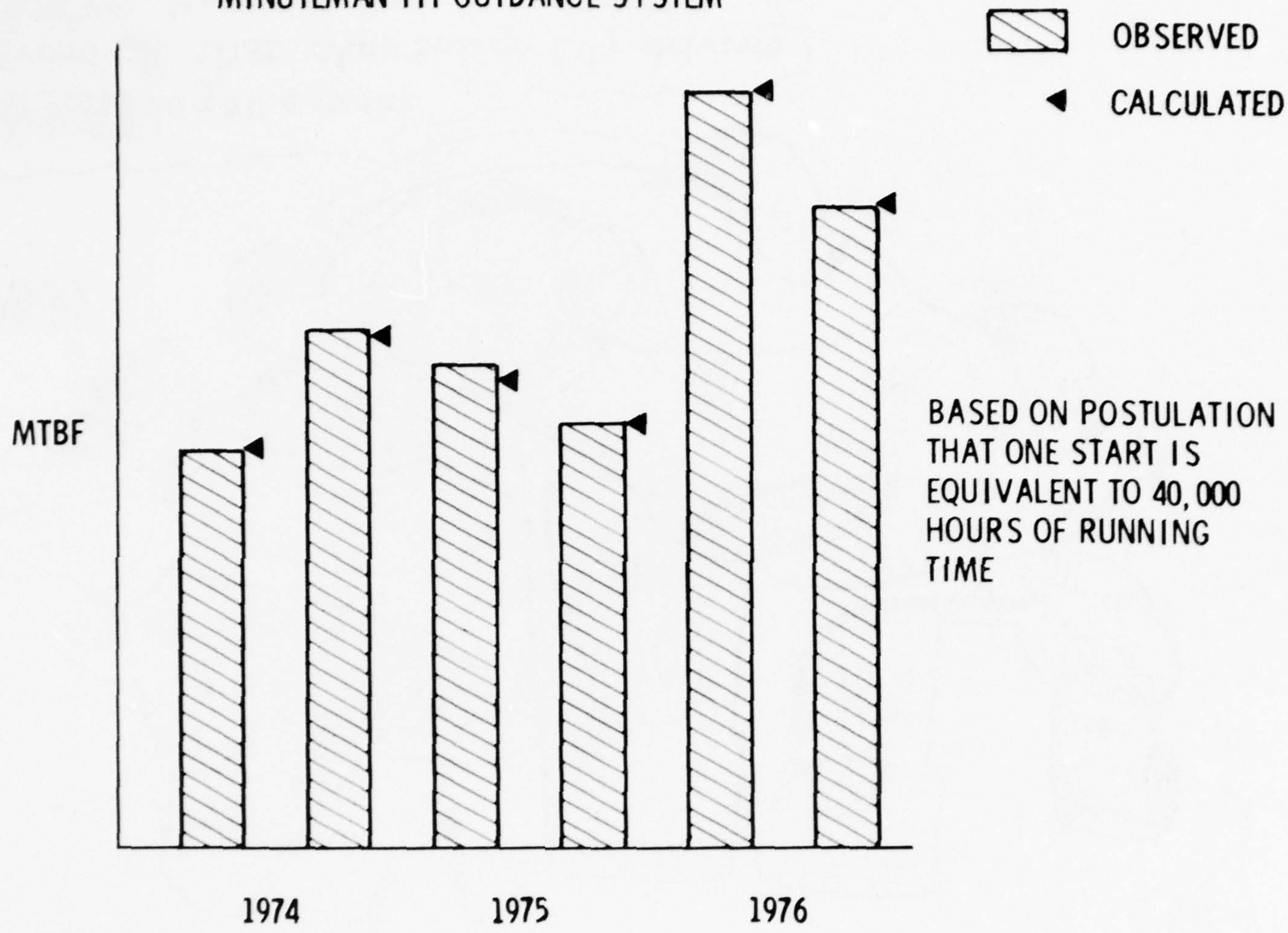
# CONCLUSION

- MANAGEMENT METHODS ARE THE KEY TO MINIMIZING LIFE CYCLE COSTS
- THE STARTING POINT MUST BE A CUSTOMER ORGANIZATION WHICH CAN BALANCE DEVELOPMENT AND O&S COSTS
- SYSTEM LEVEL INTEGRATION AND MAINTENANCE BY PROPERLY MOTIVATED PERSONNEL MUST PROVIDE TRACEABILITY FOR CORRECTIVE ACTIONS
- THE ENVIRONMENT FOR CORRECTIVE ACTIONS MUST BE CONDUCIVE TO COST EFFECTIVE DESIGN CHANGE

## THE SIGNIFICANCE OF ON-OFF CYCLES

- A DETAILED ANALYSIS OF MINUTEMAN III (APPENDIX H) HAS SHOWN THAT ONE ADDITIONAL, ON-OFF CYCLE OF THE NS20 IS EQUIVALENT IN RELIABILITY DEGRADATION TO APPROXIMATELY 40,000 HRS OF OPERATING TIME
- SAVINGS COULD BE REALIZED THROUGH MORE CONTINUOUS OPERATION OF INERTIAL SYSTEMS
- ADDITIONAL STUDIES ARE REQUIRED FOR THE PRESENTATION OF SPECIFIC RECOMMENDATIONS

COMPARISON OF CALCULATED AND OBSERVED MTBF
MINUTEMAN III GUIDANCE SYSTEM




BOY AM I SICK!
COUGH
GAS
GAS
WHAT do you expect from all that stop and go City driving you've been doing

BRIEFING TITLE

ADVANCED TACTICAL INERTIAL GUIDANCE SYSTEM

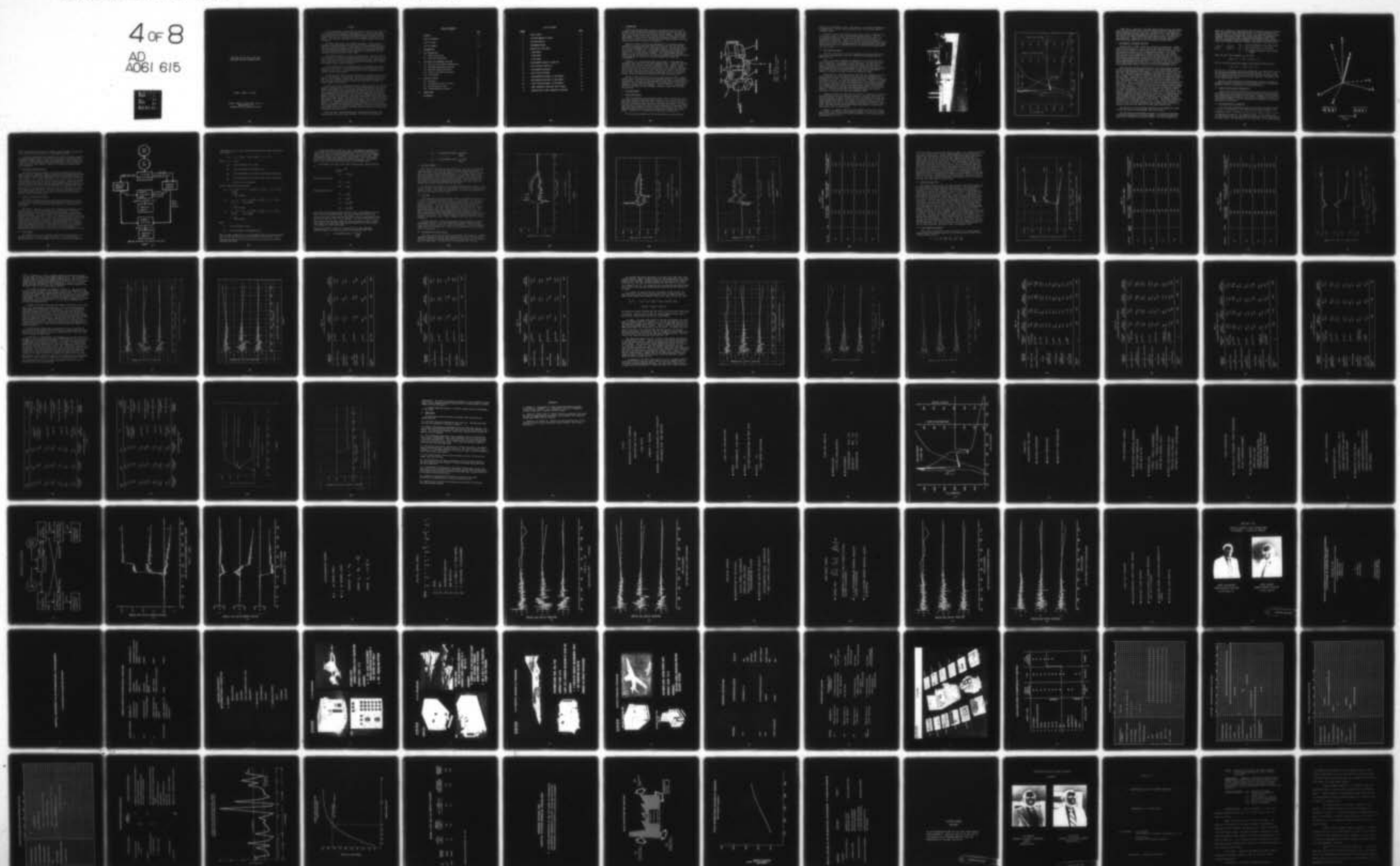
D. WALKER
CENTRAL INERTIAL GUIDANCE TEST FACILITY
HOLLOMAN AFB, NM

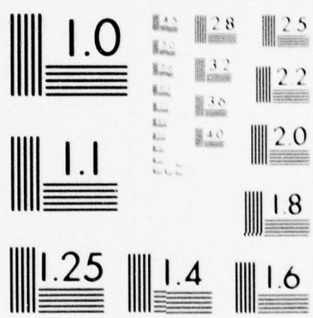
AD-A061 615 AEROSPACE GUIDANCE AND METROLOGY CENTER NEWARK AIR FO--ETC F/G 17/7
CONFERENCE PROCEEDINGS OF THE DATA EXCHANGE FOR INERTIAL SYSTEM--ETC(U)
OCT 77 E T BODEM

UNCLASSIFIED AGMC/XR-77-1 NL

4 OF 8

AD
A061 615






MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU

SLED TESTS OF THE ATIGS LASER GYRO
STRAP-DOWN INERTIAL GUIDANCE SYSTEM

AUTHOR: DONALD F. WALKER

CENTRAL INERTIAL GUIDANCE TEST FACILITY
6585TH TEST GROUP
HOLLOMAN AIR FORCE BASE, NEW MEXICO

## ABSTRACT

This paper presents the methods and results of the first sled test of a strap-down inertial guidance system which uses a triad of laser gyros. Four sled tests were conducted on the Advanced Tactical Inertial Guidance System (ATIGS) on the high speed test track located at Holloman AFB, New Mexico. The ATIGS was developed at the Naval Weapons Center, China Lake, California.

The ATIGS consisted of the following components: Three Honeywell GG1300 AE ring laser gyros, three Sundstrand Q-flex accelerometers, and a Delco Magic Model 362 computer. The computer processed the accelerometer and gyro output data through software to produce system output velocities in a computational coordinate frame appropriate for comparison with the reference data derived from the test track.

The ATIGS was mounted in a dual rail sled vehicle. Launch parameters were input to the system for alignment several minutes before the sled run After alignment the system was switched to the flight mode. ATIGS outputs were telemetered and the raw gyro and accelerometer outputs were recorded on sledborne analog magnetic recorders.

A two-stage firing sequence employing five Little John solid rockets boosted the sled vehicle at a typical maximum acceleration of 15g's to a velocity of 865 ft/sec. A water brake of -6.7g's for a duration of two seconds provided deceleration.

Telemetered data from the flight computer was available but occurred only at low frequency of about 10 Hz. The analysis methods therefore used the raw, high frequency accelerometer and gyro data recorded on the sled. This data was processed through a ground based CDC 7600 to simulate the flight computer computation.

In order to separate accelerometer errors from gyro errors, two different analysis procedures were utilized. The first method compared raw, untransformed accelerometer data to a reference function derived from test track data. Past experience has demonstrated the validity of this technique for test environments involving elastic or otherwise predictable test pallet angular motion during sled runs. The resulting difference velocities were modeled by means of regression analysis for accelerometer error coefficients and system angular motion. The second method was aimed at investigating the gyro errors. The system output velocities (namely, accelerometer data transformed to the computational coordinate frame through the use of the gyro data in a strap-down algorithm) were compared to reference test track data in the same frame. The resulting system velocity errors were again entered into regression analysis, where the model used was designed to describe both acceleration and gyro errors.

Four sled runs, five centrifuge tests (counter-rotating mode), and twelve system calibrations were performed. The ATIGS system operated

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LIST OF FIGURES

## 1. INTRODUCTION

Rocket sled and centrifuge testing of the Advanced Tactical Inertial Guidance System (ATIGS) were performed at Holloman Air Force Base for the Air Force Space and Missiles Systems Organization (SAMSO). The ATIGS test effort is a subtask of the Small Hardened Inertial Platform (SHIP) project, JON 627ANP01. The ATIGS test item and on-site technical support for the three month test effort (March through June 1976) were provided by the Naval Weapons Center (NWC), China Lake, California.

Emphasis has been placed on the development of a strap-down inertial navigator using Ring Laser Gyros (RLG) to achieve the low cost and high reliability requirements of Air Force weapon systems. A strap-down navigator provides advantages over a conventional system in that it does not require gimbals or slip rings. The gimbals are replaced mathematically by software in an on-board digital computer. Also, body-mounted inertial sensors provide the flexibility for midcourse guidance and autostabilization, eliminating the requirement for separate autopilot rate gyros and accelerometers.

Honeywell, Inc. developed the ATIGS (X-0) system, a strap-down RLG navigator, under contract to the Naval Weapons Center. Extensive laboratory and flight tests of this system were performed by NWC. Captive flight evaluations were made using an A-7E aircraft as a test vehicle. Results from the Navy tests in June 1974 and March 1975 are 4 nmi/hr average radial error in the first test series and 2.2 nmi/hr radial error in the second. The Air Force sponsored rocket-sled and centrifuge testing at Holloman to further define the dynamic performance of the RLG strap-down system.

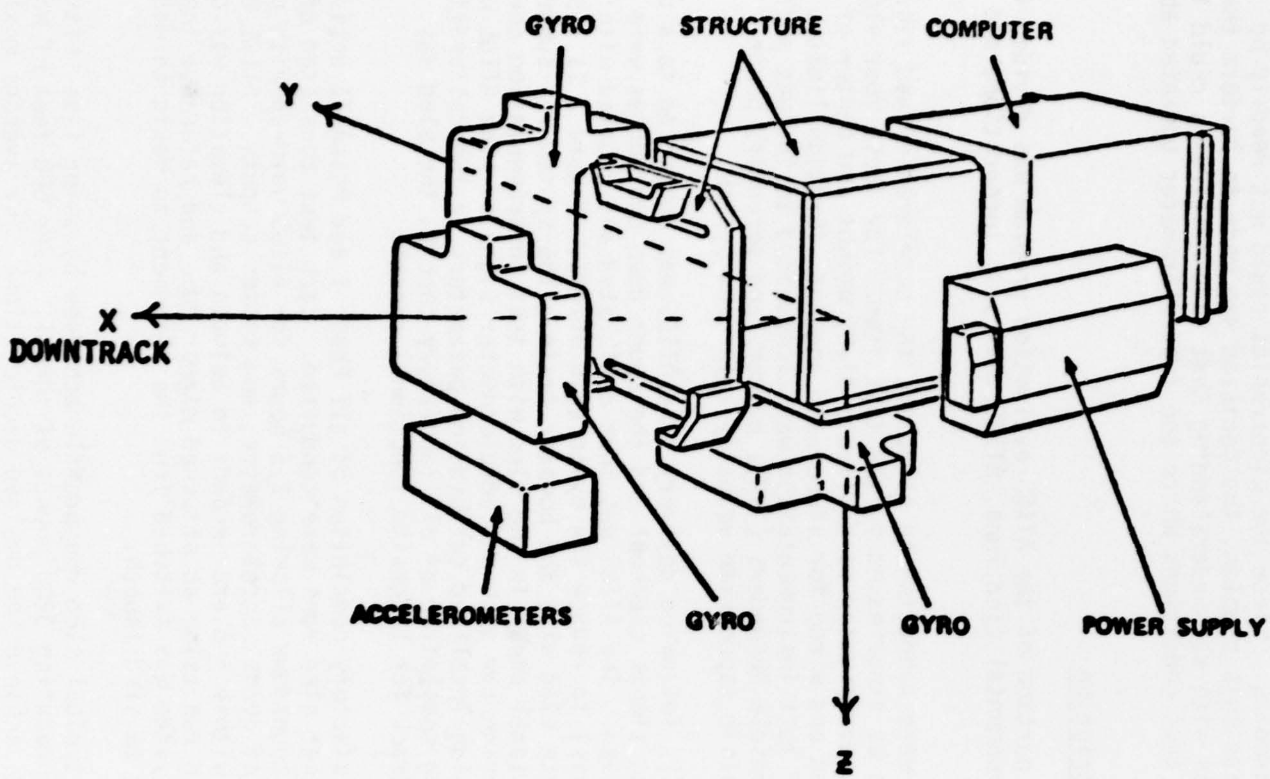
The basic ATIGS consists of an inertial measuring unit (IMU), a general purpose digital computer and ancillary equipment combined in a strap-down configuration. The inertial measuring unit utilizes three Honeywell GG-1300 ring laser gyros and three Sundstrand Q-flex accelerometers. The digital computer is a Delco Magic 362 computer. Figure 1 shows the arrangement of the ATIGS components and the orthogonal coordinate system used for ATIGS mechanization.

## 2. TEST DESCRIPTION

### 2.1 ATIGS Calibrations

ATIGS calibrations using the Naval Weapons Center equipment and procedures were performed immediately after receipt of the system at Holloman Air Force Base, after each sled run, after completion of the centrifuge tests, and after any ATIGS failures requiring a component replacement. Calibration data were used to establish baseline system performance and component alignments which were necessary for data analyses and to identify any changes in component outputs which may have been caused by the dynamic test environments. A total of 12 calibrations were conducted at Holloman AFB.

The calibration procedure and the associated data reduction program




ATIGS SYSTEM

Weight: 50 lbs.
Size: 12" long by 13" diameter
Volume: 1592 cubic inches

FIGURE 1. ATIGS SYSTEM

provide the accelerometer biases, scale factors, scale factor imbalances and orthogonalities as well as the gyro fixed drifts, scale factors, and misalignment angles.

Detailed pre-sled setup calibration data taken on the Y-accelerometer at one g-forces around its null point showed anomalous behavior. The Y-accelerometer hysteresis-type behavior was attributed to problems in the accelerometer electronics. Since the electronics could not readily be modified to eliminate this problem, the decision was made to perform the sled and centrifuge tests with the understanding that this hysteresis could induce ATIGS errors under test conditions where the Y-accelerometer operated about its zero-g point.

## 2.2 Sled Test Description

The sled test portion of the ATIGS evaluation program was divided into three phases; environmental sled runs, ATIGS test site integration, and ATIGS sled runs.

Phase I tests were conducted to establish the acceleration and vibration environment to be experienced by the test item. For these four sled runs, a dummy mass, constructed to duplicate ATIGS weight and center of gravity, was mounted and wired for linear and angular vibration limits, proper operation of test instrumentation was ascertained to include performance of the Test Vehicle Recorders (TVR), primary and secondary power supplies, and the basic sapce-time velocity reference system.

During Phase II, following delivery, the ATIGS was subjected to a complete laboratory functional checkout and the count down procedures were developed and verified. The ATIGS was then calibrated and mounted within the sled (down-track axis) to reduce the hysteresis errors. Figure 2 is a photograph of the complete sled with the booster train. The system was subjected to a complete functional check in the sled with test instrumentation checkout including measuring raw gyro and accelerometer signals. The ATIGS was again calibrated using localized calibration parameters in the calibration routines. Following completion of all laboratory checks, the sled was positioned on the track for tracksite functional checks.

Following satisfactory completion of all Phase I and Phase II activities, four high-speed rocket sled runs were conducted. Each test consisted of a detailed prelaunch countdown allowing 2.5 hours for ATIGS warm-up with continuous monitoring of gyros, accelerometer, and system outputs. ATIGS down-track alignment to within $\pm$ 6 arc-seconds in azimuth and elevation was obtained prior to each run using an attached mirror cube and reference theodolites. The ATIGS system was switched from the alignment to navigate mode three minutes prior to sled launch.

Figure 3 is a typical sled run profile achieved by using five "Little John" motors, each producing 3200 pounds of thrust. Over 600 feet of water braking were used to achieve the desired deceleration. The average maximum deceleration was -6.7 g's.

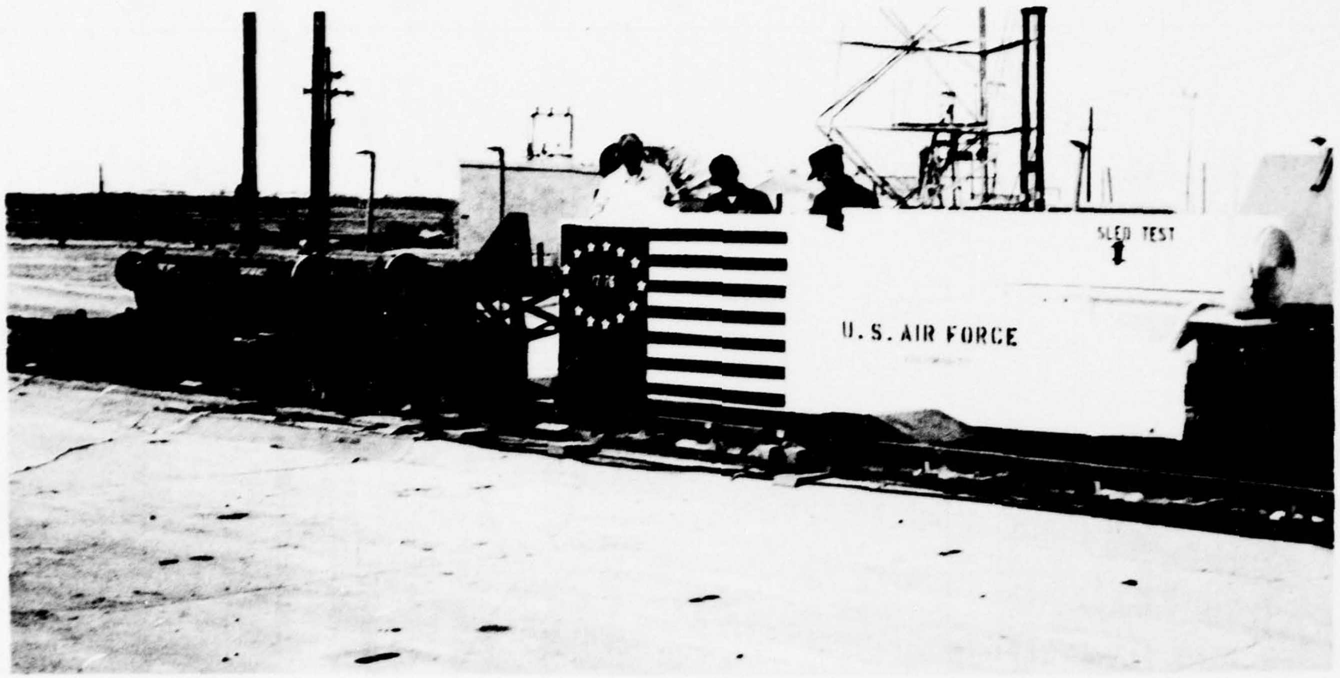



FIGURE 2

Sled and Booster at Track

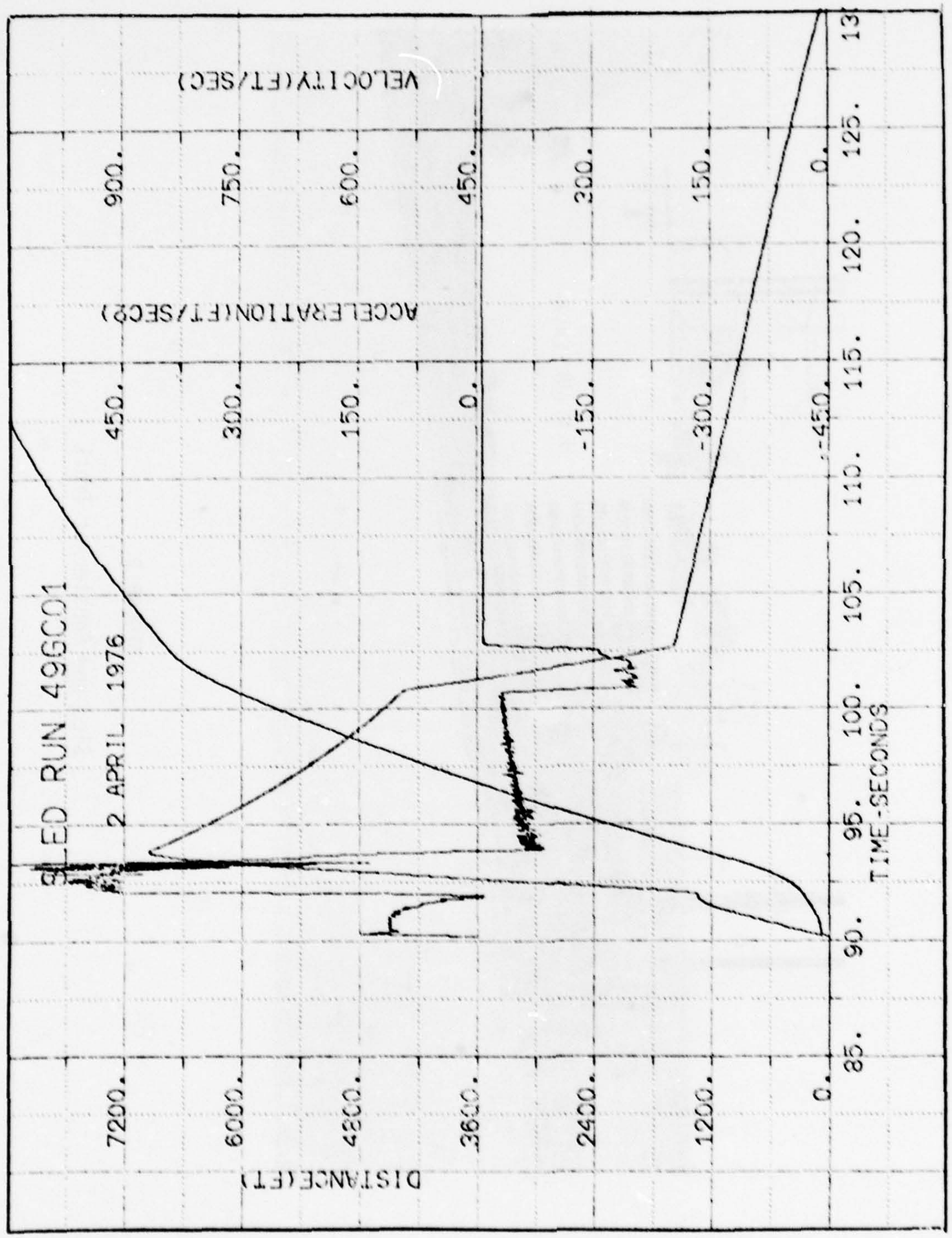

SLED RUN 49GC01
2 APRIL 1976
DISTANCE(FT)
ACCELERATION(FT/SEC2)
VELOCITY(FT/SEC)
TIME-SECONDS

FIGURE 3

ATIGS signals, comprised of the PCM computer output and the raw accelerometer and gyro outputs, were recorded in conjunction with a precision sled-borne timing source and the space-time reference system. Sled down-track position and velocity measurements were accurate to .03 ft over 20000 ft and .004 ft/sec (one sigma) respectively, with timing accurate to better than one microsecond. Comparison of the ATIGS signals with the space-time reference system formed the basis for evaluating the ATIGS system.

## 3. SLED ANALYSIS PROCEDURES AND DATA

The main topics of this section are divided into three areas: signal handling, data processing, and the analysis and model derivation. The first topic covers the types of system signal outputs and how these signals were electronically recorded on the instrumentation equipment. The second section discusses the ground-based computer processing of the sled test data; the main points emphasized are the strap-down algorithm, gyro and accelerometer compensations, and the reference frame derivations. The third topic highlights the analysis methodology and model derivation for the observed accelerometer and system errors. In particular, the errors occurring in the ATIGS accelerometers alone will be identified separately from the total system errors, which include both gyro and accelerometer errors.

ATIGS data was available from two sources; the flight computer outputs and the raw gyro and accelerometer outputs. The flight computer outputs were Pulse Code Modulated (PCM) signals. The PCM signals occurred at a rate of 10 Hz. The raw gyro and accelerometer pulses were the second source of data. These pulses represented respective increments of velocity and gyro position angle. Data rates of several kHz were used for component evaluation. The space-time reference pulses represented sled position during the sled run. Interrupters (steel blades) were precisely located along the entire length of the track. Interrupters broke a sledborne light beam producing the data pulses. The ATIGS and space-time data were recorded by sledborne magnetic tape recorders. The ATIGS PCM data were also telemetered and recorded at the track blockhouse. After each sled run, the sled data was converted to a digitized computer word format by the General Input Converter (GIC) facility. Leading edges of the pulses or events, such as gyro pulses, were timed to a resolution of 500 nano-seconds at the GIC. A chronological record of event times was recorded on tape in the form of 48 bit computer words. Eight different signals (three accelerometers, three gyros and two space-time pulse trains) were processed in this manner. The magnetic tape was transmitted to Kirtland AFB via a 50 KB data link. Data processing was then performed using a CDC 7600 computer setup. The use of the ground based computer, with the higher data sample rates, provided better accuracy and resolution than could be obtained from the flight computer data.

The definition of the strap-down algorithm and the compensation terms for both the gyros and accelerometers are now presented.

The body-mounted accelerometers and gyros, in conjunction with math computations performed by the flight computer, eliminate the gimbals and slip rings of conventional navigation system. The digitized gyro data

served as a reference for the accelerometers by providing angle rate information. This angular rate information is used to build a coordinate transformation matrix or direction cosine matrix. The continual updating of this direction cosine matrix enables the acceleration pulses, increments of velocity, to be resolved into a computational navigation frame. These velocity increments are then accumulated in the standard navigation frame as north, east and down velocities. The basic algorithm can be expressed as

$$\int_t^{t+\Delta t} A_n d\tau = \int_t^{t+\Delta t} MA_r d\tau$$

$A_n$ = (3x1) accelerations in navigation frame

$A_r$ = (3x1) accelerations in body frame

$M$ = (3x3) body to navigation transformation matrix

where for small time increments, we can write

$$\Delta V_n(t + \Delta t) = M(t + \Delta t)\Delta V_r(t + \Delta t)$$

The V's are then accumulated to update the navigation frame velocities.

$$V_n(t + \Delta t) = V_n(t) + V_n(t + \Delta t)$$

The gyro and accelerometer data were interpolated to a common time series on the ground based computer before entering the algorithm. A small $\Delta t$ step size of 2500 microseconds was used. The step size kept the amount of data to a reasonable limit and also avoided errors caused by a low updating rate of the transformation matrix.

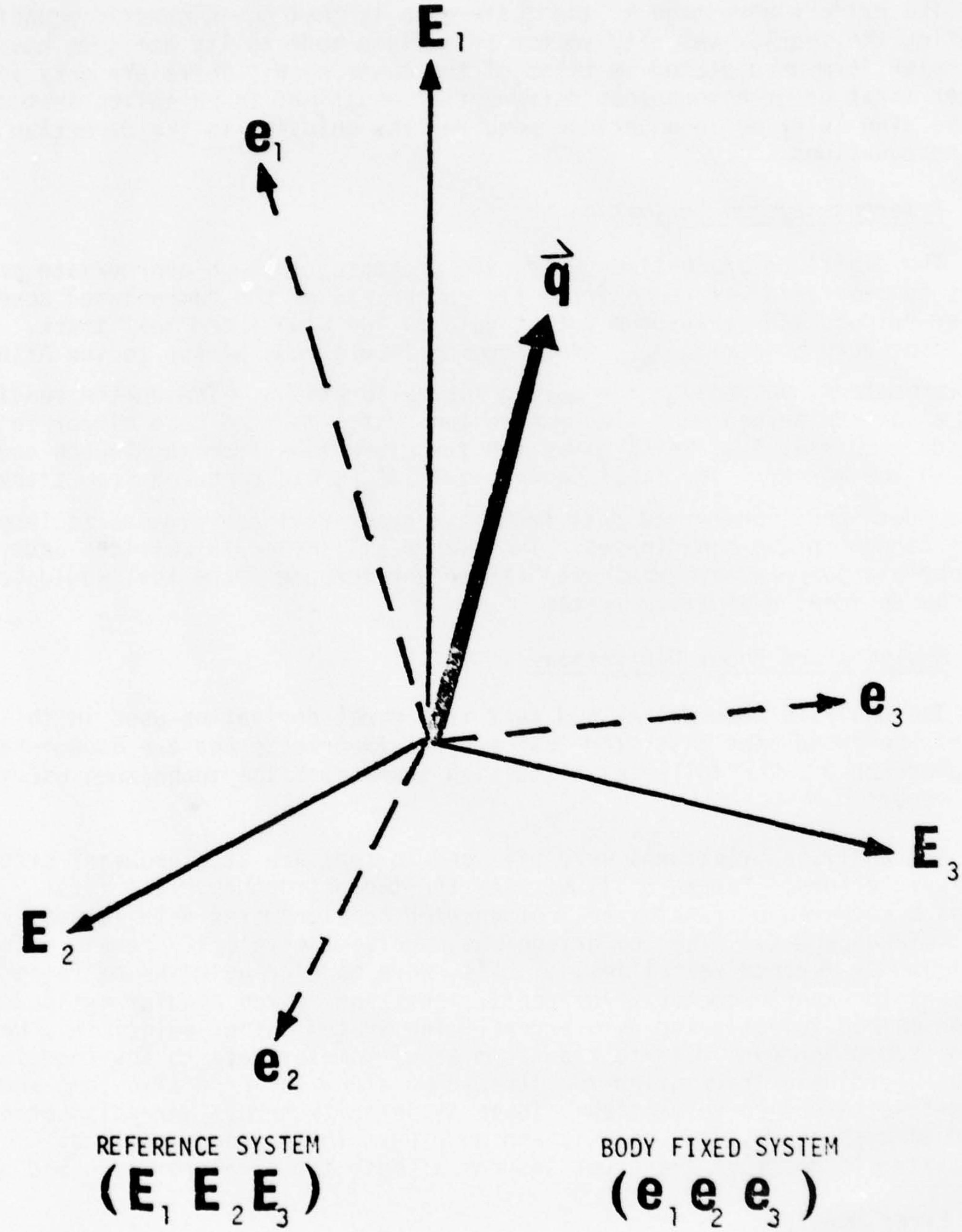
The basic program equations were obtained from the flight program requirement documents prepared for the Naval Weapons Center by the Honeywell Aerospace Division, St. Petersburg, Florida (Reference 1).

### 3.1 Gyro and Accelerometer Compensation

Significant errors were removed from the digitized gyro and accelerometer data by using coefficients established during the calibration process. Gyro compensation was provided for scale factor, alignment and fixed drift. Accelerometer compensation was for scale factor, alignment, fixed drift and scale factor unbalance. Once the compensation was completed, the attitude quaternion was calculated.

### 3.2 Attitude Quaternion Generation

One of the more interesting features of the ATIGS strap-down algorithm is the use of quaternions or four dimensional hypercomplex numbers. The orthonormal frames, a reference ($\vec{E}_1$, $\vec{E}_2$, $\vec{E}_3$) and a body fixed ($\vec{e}_1$, $\vec{e}_2$, $\vec{e}_3$), are presented in Figure 4. The quaternion vector, $\bar{q}$, lies along an axis of rotation about which the body could be rotated to become aligned with the reference system. The magnitude of $\bar{q}$ is $\sin\phi/2$ where $\phi$ is the angle through




QUATERNION VECTOR $\vec{q}$

FIGURE 4

which the reference system must be rotated to become aligned with the body and is positive in the direction of a right-handed rotation.

The primary advantage of the quaternion is that the kinematic equations relating the angular velocity vector of a rigid body to its attitude have a simpler form when stated in terms of the quaternion. There are only four linear first order homogeneous differential equations to be solved instead of the nine Euler angle equations required for solution in the direction cosine equations.

## 3.3 Reference System Derivation

The digitized space-time pulses are processed through appropriate programs to provide a reference frame for comparison of the compensated accelerometer putputs and strap-down output data to the high speed test track. For this procedure a matrix, $A_{MA}$, transforming from a cube mirror to the ATIGS accelerometers, was solved for during the calibrations. Theodolite readings were also made before each sled run on the system mounted cube mirror to provide a matrix, $A_{IM}$, which gives the transformation from the launch coordinate to the mirror. The final known matrix, $A_{RL}$, was computed from track survey data and transformed data from test track rail coordinates to launch point tangent plane coordinates. The use of all these 3x3 matrices and appropriate computer programs established a reference frame that would be seen by an ideal navigation system.

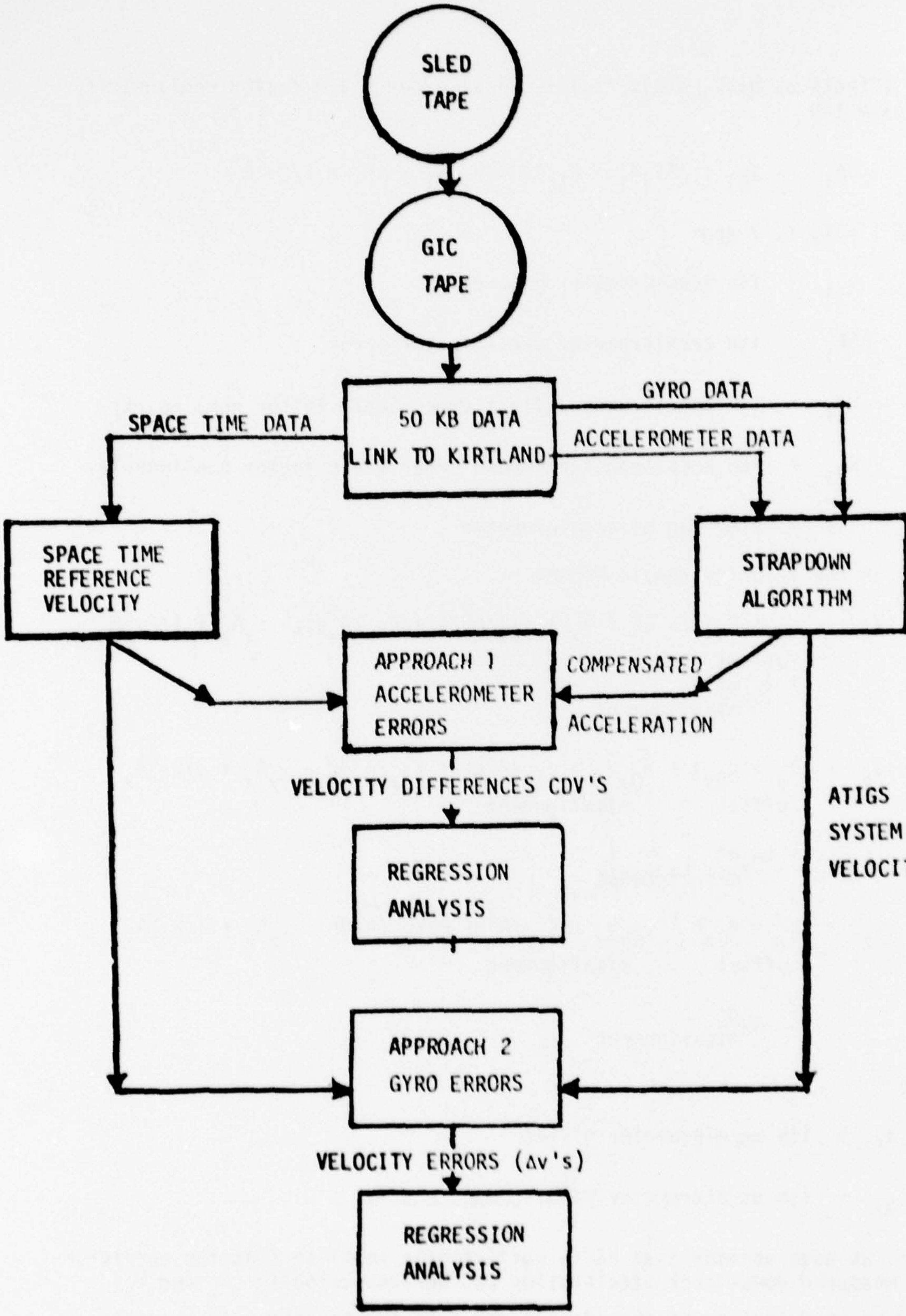
## 3.4 Analysis and Model Derivations

The analysis methodology and test item model derivation used in this report are based upon past sled test project experience and are documented in Reference 2. The following discussion summarizes the techniques used in this report.

Two analysis procedures were utilized to separate accelerometer errors from gyro errors. Figure 5 illustrates the two approaches. The first approach compared untransformed, compensated accelerometer data to space-time reference data. The comparison was made in the velocity domain. The resulting difference velocities, or DV's, were modeled by means of regression analysis for accelerometer error coefficients and system angular motion. The second method investigated gyro errors. The system output velocities, derived from using gyro data to transform accelerometer data to the computational coordinate frame using the strap-down algorithm were also compared to space-time reference velocities. These $\Delta V$ velocity errors were also processed through regression analysis and modeled. This second model was formulated to describe the error sources of both the accelerometers and gyros.

## 3.5 Error Models

The formulation of the two separate models for the accelerometer errors and the system errors (which include gyro errors) are presented in the following section. The accelerometer errors $\delta A_i$ are usually attributable to




ANALYSIS APPROACHES TO EVALUATE ATIGS DATA

FIGURE 5

such effects as bias, scale factor, first order scale factor nonlinearity and time lag.

$$\delta A_i = K_{0i} + \delta SF_i A_i + K_{1i} A_i^2 + K_{2i} A_i^3 - \tau \dot{A}_i + 1/2 \tau^2 \ddot{A}$$

where $i$ = X, Y, Z and

$K_{0i}$ = ith accelerometer bias error

$\delta SF_i$ = ith accelerometer scale factor error

$K_{1i}$ = ith accelerometer first order scale factor nonlinearity

$K_{2i}$ = ith accelerometer second order scale factor nonlinearity

$\tau$ = time lag of accelerometer

which in the velocity domain become

$$\delta V_x = \underbrace{K_x}_{\text{offset}} + K_{0x} t + \delta S \cdot F \cdot \hat{V}_x + K_{1x} \int \hat{A}_x^2 dt + K_{2x} \int \hat{A}_x^3 dt - \tau_x \hat{A}_x + 1/2 \tau_x^2 \dot{\hat{A}}_x + \underbrace{\theta_{0y} gt}_{\text{misalignment}}$$

$$\delta V_y = \underbrace{K_y}_{\text{offset}} + K_{0y} t + \underbrace{\theta_{0z} \hat{V}_x}_{\text{misalignment}} + K_{1y} \int \hat{A}_x^2 dt + K_{2y} \int \hat{A}_x^3 dt - \tau_y A_x + 1/2 \tau_y^2 \dot{\hat{A}}_x + \underbrace{\theta_{0x} gt}_{\text{misalignment}}$$

$$\delta V_z = \underbrace{K_z}_{\text{offset}} + K_{0z} t + \underbrace{\theta_{0y} \hat{V}_x}_{\text{misalignment}} + K_{1z} \int \hat{A}_x^2 dt + K_{2z} \int \hat{A}_x^3 dt - \tau_z \hat{A}_x + 1/2 \tau_z^2 \dot{\hat{A}}_x + \underbrace{{}_{0x} gt}_{\text{misalignment}}$$

Where

$K_i$ = ith accelerometer offset

$\theta_{0i}$ = ith accelerometer misalignment angle.

NOTE: We have assumed that $\delta A$ is sufficiently small so that the accelerometer measured down-track acceleration and derived velocity ($\hat{A}_x$ and $\hat{V}_x$) could be used instead of the ideal A and V in the equations to generate coordinate functions.

It must be pointed out that the Y and Z accelerometers, mounted with a 30 roll about the x axis, changed attitude as the pallet fixture moved because of the sled acceleration and deceleration. The Y and Z accelerometers sensed these motions as sine components of the down-track velocity. These accelerometer motions then showed up as large errors. The x accelerometer also senses the sled motion but because the error involves a cosine term there is very little error observed in the X accelerometer value.

Accelerometer error due to test pallet angular motion can be expressed as

$$\theta_{Dynamic} = KA_x$$

$$\delta A_z = \sin\theta_{1z}A_x$$

thus for small angles

$$\delta A_z = \theta_{1z}A_x$$

$$\delta A_y = \theta_{1y}A_x$$

Then substituting for $\theta$

$$\delta A_z = K_{1y}A_x^2$$

$$\delta A_y = K_{1y}A_x^2$$

$$\delta V_z = K_{1z}\int A_x^2 dt$$

$$\delta V_y = K_{1y}\int A_x^2 dt$$

which indicates that for the major portion of the Z accelerometer error and part of the Y accelerometer error, the $K_{1z}K_{1y}$ coefficients describe the dynamic pitch angle rather than the first order scale factor nonlinearity as $K_{1x}$ does for the case of the X accelerometer. The terms $K\int A^3 dt$ and $\theta gt$ were later removed from the model. These two terms provided very small contribution values to the total error and could be omitted from the linear regression without any significant change.

The gyro error model, because it involved fitting of the strap-down algorithm outputs, contained both gyro and accelerometer model terms.

$$\Delta V_x = \text{x accelerometer terms} - \underset{\text{Drift}}{1/2 g w_{0y} t^2}$$

$$\Delta V_y = y \text{ accelerometer terms} - \underset{\text{Drift}}{w_{0z}} \int A_x tdt$$

$$\Delta V_z = z \text{ accelerometer terms} + \underset{\text{Drift}}{w_{0y}} \int A_x tdt$$

## 4. SLED TEST RESULTS

This section is divided into four main areas: gyro data, accelerometer velocity errors, system velocity errors, and linear regression analysis. A short discussion of the gyro data centers on the fact that three of the four sled runs produced repeatable results (Run #2 gyro data was questionable). The accelerometer velocity errors indicate the dynamic ATIGS motions, while the system velocity errors show how well the gyros perform in removing the accelerometer sensed errors due to dynamic motions. The final discussion topic covers the modeling performed on the respective velocity errors and demonstrates how well the model fits the test data.

The results from sled Run #1 are presented throughout this section. This run was selected as the main test case because it produced the best regression analysis results. Data from the remaining three sled runs are summarized in the appropriate tables in this section.

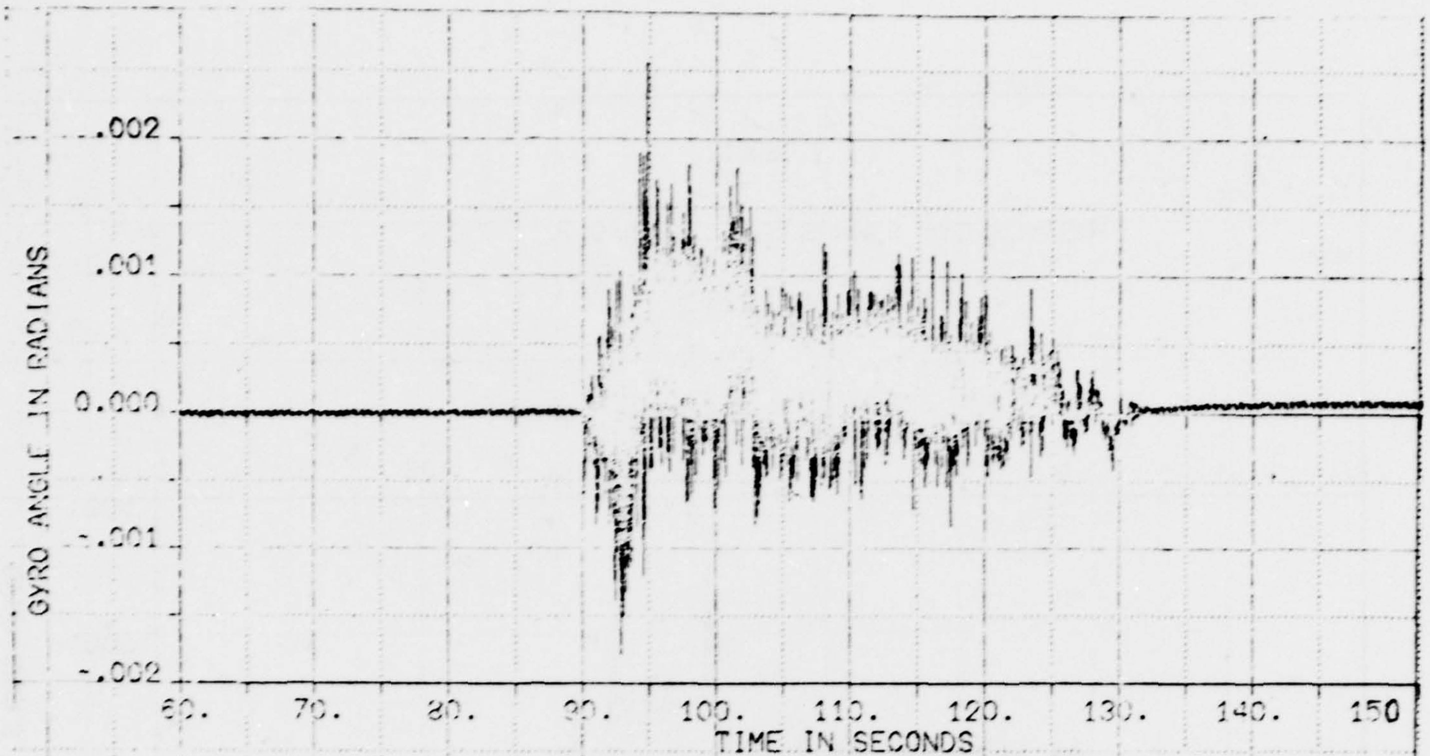
### 4.1 Gyro Data

The orientation of the body mounted sensors is recalled at this point as it will aid in interpreting the gyro data. As mentioned in the sled test description, a 30 degree roll angle was implemented to avoid Y-accelerometer hysteresis effects. A plot of the compensated X-gyro data for Run #1 is shown in Figure 6. Minor roll angles occurred at motor burnout and at the end of water brake. The pitch angle information from the Y-gyro, Figure 7, had maximum angular excursions several times larger than the X-gyro. The shape of the Y-gyro data closely followed the sled acceleration profile. This resemblance was used in validating some of the coordinate function coefficients in the model. The Z-gyro, Figure 8, indicated a yaw offset angle when the sled came to a stop. Table I summarizes the gyro data for all four sled runs.

Gyro data from Run #2 appeared questionable and was therefore excluded from further analysis. The X and Z-gyro offset angles for the run were significantly larger than those recorded for other runs. The Z-gyro offset angle also had a different sign. Later results substantiate the uncertainty in Run #2 gyro data.

### 4.2 Accelerometer Velocity Errors

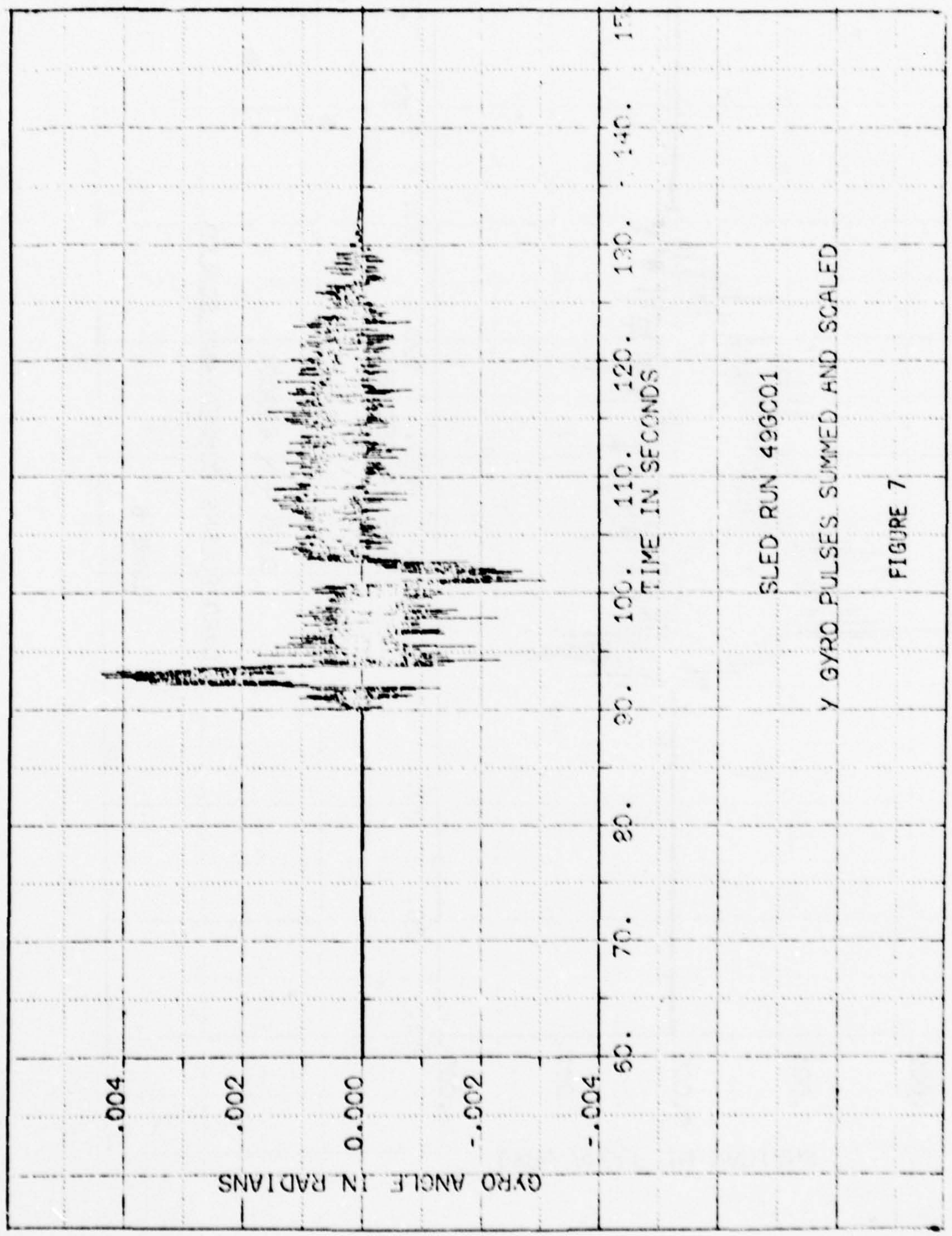
The launch position of the ATIGS accelerometers was measured by recording theodolite readings of a mirror cube mounted to the system. This provided a check on system self-alignment operation and also gave more accurate prelaunch yaw angle measurement. For Run #1 the X-accelerometer velocity error




SLED RUN 496C01

X GYRO PULSES SUMMED AND SCALED

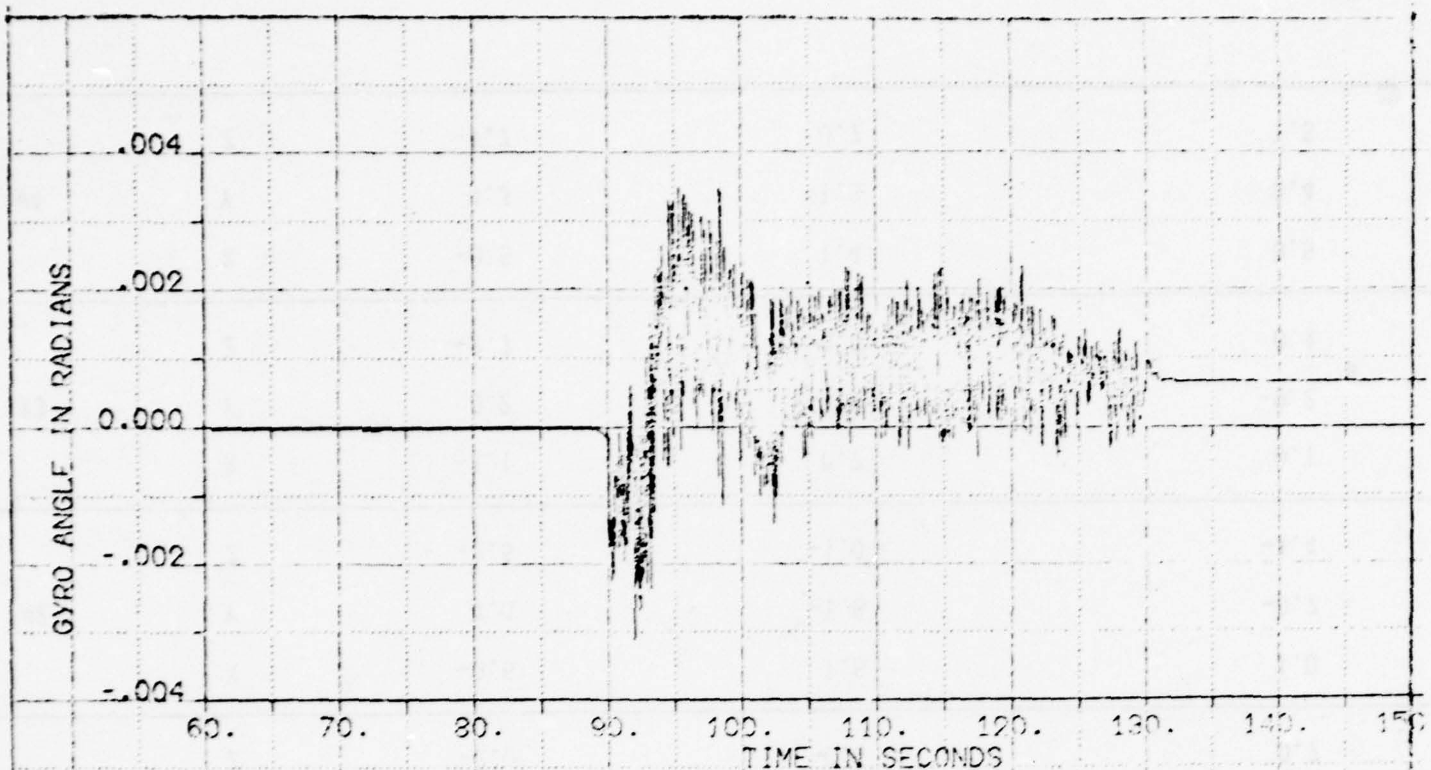
FIGURE 6




SLED RUN 49GC01

Y GYRO PULSES SUMMED AND SCALED

FIGURE 7




SLED RUN 490001

Z GYRO PULSES SUMMED AND SCALED

FIGURE 8

TABLE I

SLED GYRO DATA SUMMARY

| SLED RUN | GYRO | VALUE AT BOOST IN MILLIRADIANS | VALUE AT WATER BRAKE IN MILLIRADIANS | VALUE AT SLED STOP POINT IN MILLIRADIANS |
|---|---|---|---|---|
| | X | -1.0 | 1.3 | 0.1 |
| #1 | Y | 3.9 | -2.0 | 0.0 |
| | Z | -2.0 | -0.5 | 0.7 |
| | X | -0.5 | 1.8 | 1.0 |
| #2 | Y | 4.0 | -1.8 | -0.7 |
| | Z | -2.5 | -1.0 | -1.4 |
| | X | -1.1 | 0.7 | 0.1 |
| #3 | Y | 3.2 | -1.5 | -0.2 |
| | Z | -2.7 | 0.7 | 0.4 |
| | X | -0.5 | 1.4 | 0.5 |
| #4 | Y | 4.3 | -1.3 | 0.4 |
| | Z | -1.7 | 0.7 | 1.5 |

(Figure 9) showed a system position change at launch. The remaining x-velocity error ($DV_x$) retained this constant slope throughout the sled run and after completion of sled motion. A check on the Y-gyro final offset angle was performed. The angle derived from the gravity component sensed by the X-accelerometer, at the end of each sled run, agreed closely with the Y-gyro offset angle in all runs except Run #2. The Y-accelerometer velocity error ($DV_y$) looked different for each sled run. This was probably caused by non-repeatable cross-track motion and vibration. The Y-accelerometer measured some of the sled-induced pitch angle and therefore had a positive $DV_y$ value at the end of the sled run. The Z-accelerometer velocity error ($DV_z$), which was caused almost entirely by pitch motion, had a large positive value at launch and increased in value at water brake. This step-shaped error can be described by the coordinate function integral $A_x$ squared where $A_x$ is the down-track acceleration. A compilation of all sled run DV's values are found in Table II. This table displays repeatable accelerometer errors in $DV_x$ and $DV_z$ and shows the wider range of values in $DV_y$.

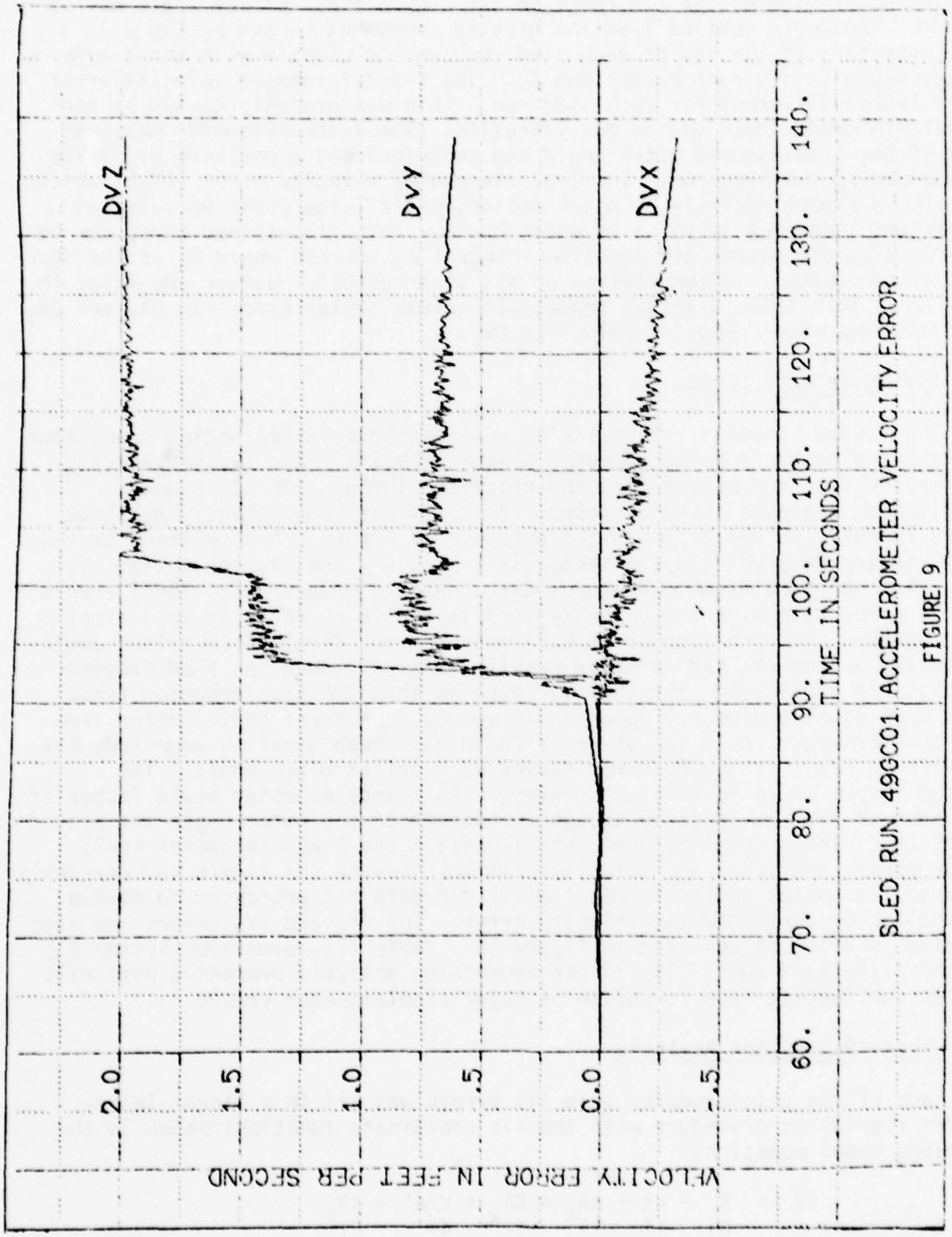
## 4.3 System Velocity Error

The system velocity errors ($\Delta V$'s) were formed by differencing space-time reference velocity from the computed system velocity. The system velocity was derived from raw sensor data and processed through the strap-down algorithm on a ground based computer. The $\Delta V$'s were consistently negative. Figure 10 for sled run #1 shows the negative V errors. A comparison of the accelerometer $DV_x$, which was essentially a sloping line, to the system $\Delta V_x$ shows that the accelerometers and/or gyros have introduced additional errors. The $\Delta V_x$ error resembles the velocity profile and is essentially zero after water brake. The gyros appear to have measured the final pitch offset angle correctly, as the $\Delta V_x$ had no major gravity component when the sled stopped. A reasonable explanation for the $\Delta V_x$ shape is that two accelerometer error terms were equal and nearly opposite in value. The error contribution from an X-accelerometer scale factor error could have been equal in magnitude but opposite in sign, to the DV error caused by a pallet pitch angle. The maximum Y-gyro angle is only .22 degrees. An X-accelerometer scale factor of the order of 230 ppm is large enough to counteract the pitch angle and provide a flat $DV_x$. The system $\Delta V_x$ would still contain the X-accelerometer scale factor error, and hence the velocity profile, because the Y-gyro had correctly measured the pallet motion. Actual ATIGS PCM data was processed to form a $\Delta V_x$ and it too contained the velocity error. The $\Delta V_y$ and $\Delta V_z$ errors are also negative in value as observed in Figure 10. Table III summarizes system V's for the ATIGS sled runs. The linear regression analysis presented next will tend to substantiate the postulate of major accelerometer errors.

## 4.4 Linear Regression Analysis

Each of the accelerometer velocity errors was fit in a linear least-squares regression procedure with the six coordinate functions shown in the following model equation.

$$\Delta V = K_{0i} + K_{1i}t + K_{2i}\hat{A}_x + K_{3i}\hat{\dot{A}}_x + K_{4i}\int\hat{A}^2 + K_{5i}\hat{V}_x$$




SLED RUN 49GC01 ACCELEROMETER VELOCITY ERROR

FIGURE 9

TABLE II

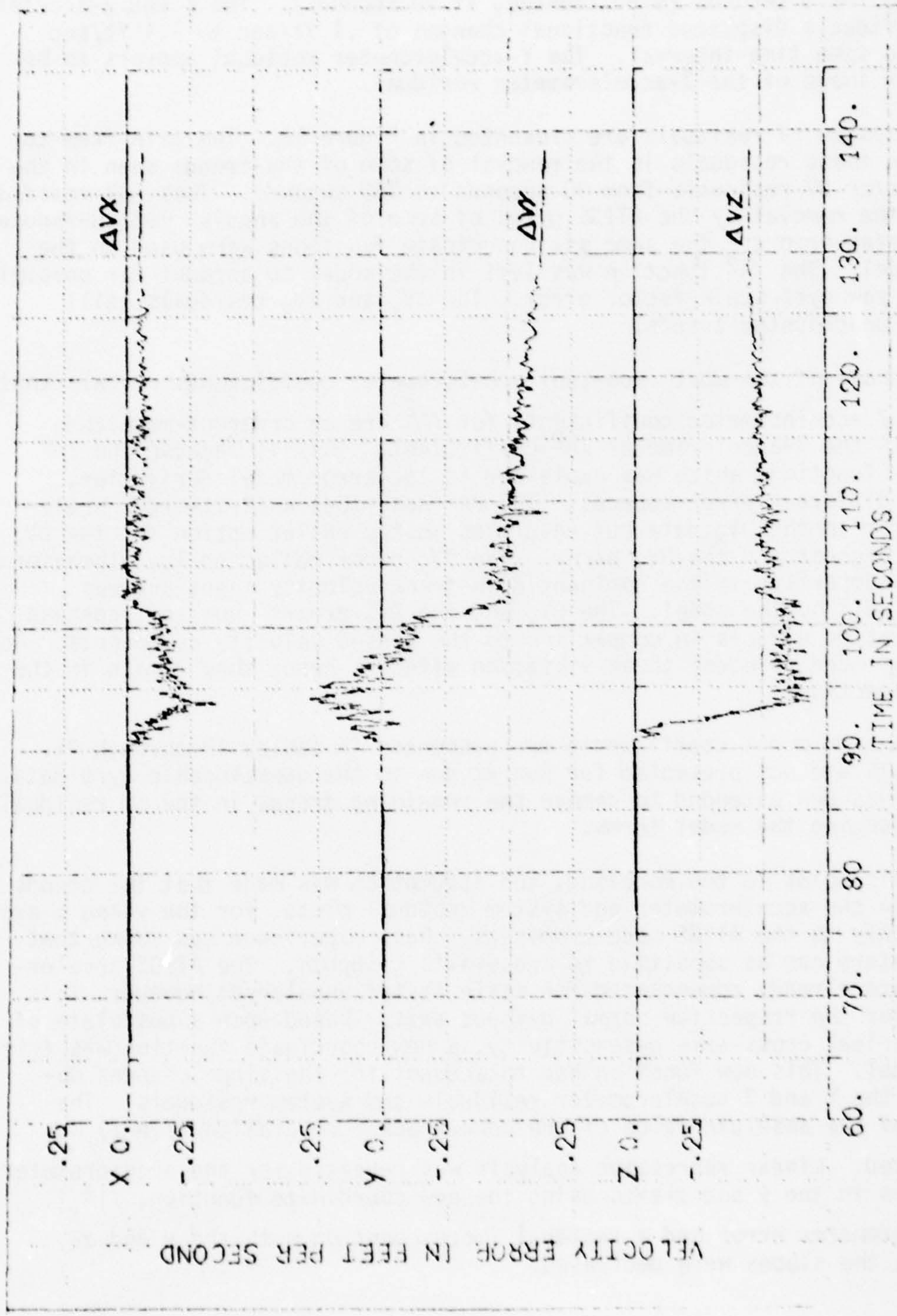
ACCELEROMETER DV ERROR SUMMARY

| SLED RUN | ACCELER-OMETER | VALUE AT BOOST IN FEET/SECOND | VALUE AT WATER BRAKE IN FEET/SECOND | VALUE AT SLED STOP POINT IN FEET/SECOND |
|---|---|---|---|---|
| | X | - .025 | - .100 | - .225 |
| #1 | Y | .725 | .700 | .650 |
| | Z | 1.325 | 1.925 | 1.975 |
| | X | - .075 | - .025 | - .225 |
| #2 | Y | .750 | .375 | .200 |
| | Z | 1.600 | 1.500 | 1.425 |
| | X | - .050 | - .025 | - .425 |
| #3 | Y | .325 | 1.075 | 1.250 |
| | Z | 1.425 | 1.450 | 1.450 |
| | X | - .075 | - .075 | - .450 |
| #4 | Y | - .550 | .500 | .575 |
| | Z | 2.150 | 2.000 | 2.000 |

TABLE III

ATIGS ΔV ERROR SUMMARY

| SLED RUN | SYSTEM | VALUE AT BOOST IN FEET/SECOND | VALUE AT WATER BRAKE IN FEET/SECOND | VALUE AT SLED STOP POINT IN FEET/SECOND |
|---|---|---|---|---|
| | X | -.225 | 0. | - .075 |
| #1 | Y | .225 | - .425 | - .575 |
| | Z | -.625 | - .600 | - .450 |
| | X | -.275 | - .100 | - .450 |
| #2 | Y | .075 | - .200 | .950 |
| | Z | -.450 | - .800 | -1.35 |
| | X | -.225 | .025 | -.050 |
| #3 | Y | -.450 | - .300 | - .625 |
| | Z | -.300 | - .625 | - .550 |
| | X | -.250 | - .050 | - .050 |
| #4 | Y | -.600 | - .750 | - .625 |
| | Z | -.150 | - .375 | - .450 |




SLED RUN 496C01 ATIGS VELOCITY ERROR

FIGURE 10

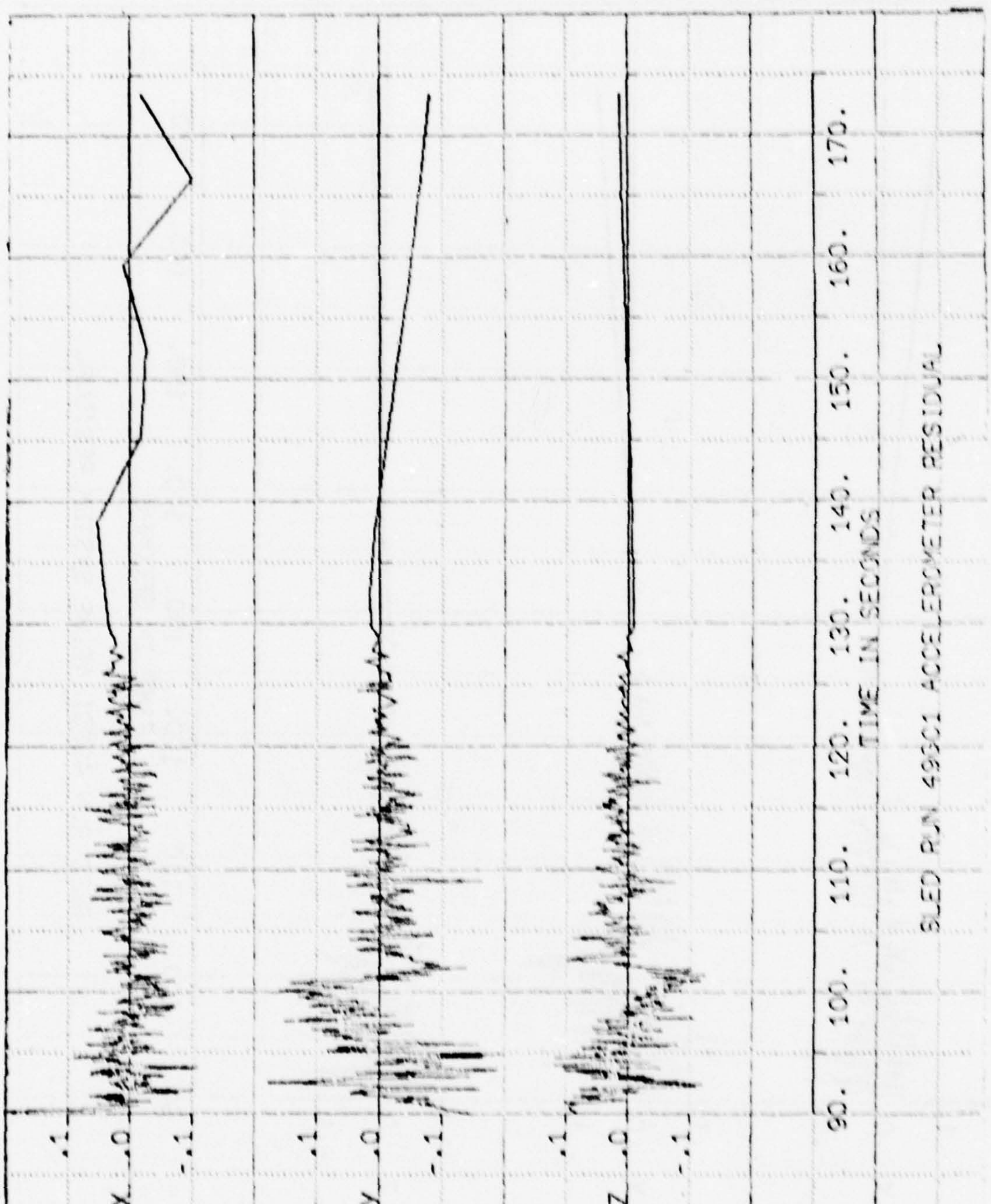
Figure 11 shows the x, y, and z residual velocity errors after using this six term model for Run #1 accelerometer velocity errors. The X-accelerometer residual shows minor functional changes between the time interval of 95 seconds to 102.5 seconds (sled launched at 90 seconds). The Y and Z-accelerometer residuals displayed functional changes of .1 ft/sec to -.1 ft/sec during the same time interval. The Y-accelerometer residual appears to be the mirror image of the Z-accelerometer residual.

The system $\Delta V$ residuals are presented in Figure 12. The main item to observe in these residuals is the removal of some of the trends seen in the accelerometer DV residuals from 90 seconds to 100 seconds. Thes $\Delta V$ residuals indicate the removal by the ATIGS gyros of some of the angular motion-induced accelerometer errors. The same six coordinate functions were used in the system model. The $\int A^2$ function was left in the model to account for possible pitch and yaw gyro scale factor error. The $\Delta V_y$ and $\Delta V_z$ residuals still contained unaccounted trends.

A summary of the most important accelerometer coefficients reveals that the Y and Z accelerometer coefficients for $\int A^2$ are an order-of-magnitude larger than the X-accelerometer $\int A^2$ coefficient. This is because the $\delta A^2$ coordinate function, which was explained in the error model derivation, describes different error sources. The $\int A^2$ describes a first-order scale-factor error in the $DV_x$ data but describes mostly pallet motion for the $DV_x$ error and highest for the $DV_y$ error. The $DV_x$ error reflected low vibrational inputs in comparison to the dominant down-track velocity input and was described well by the model. The $DV_y$ and the $DV_z$ errors, however, contain large vibration effects in comparison to the sensed velocity components. No attempt was made to model these vibration effects; hence they remain in the residual functions.

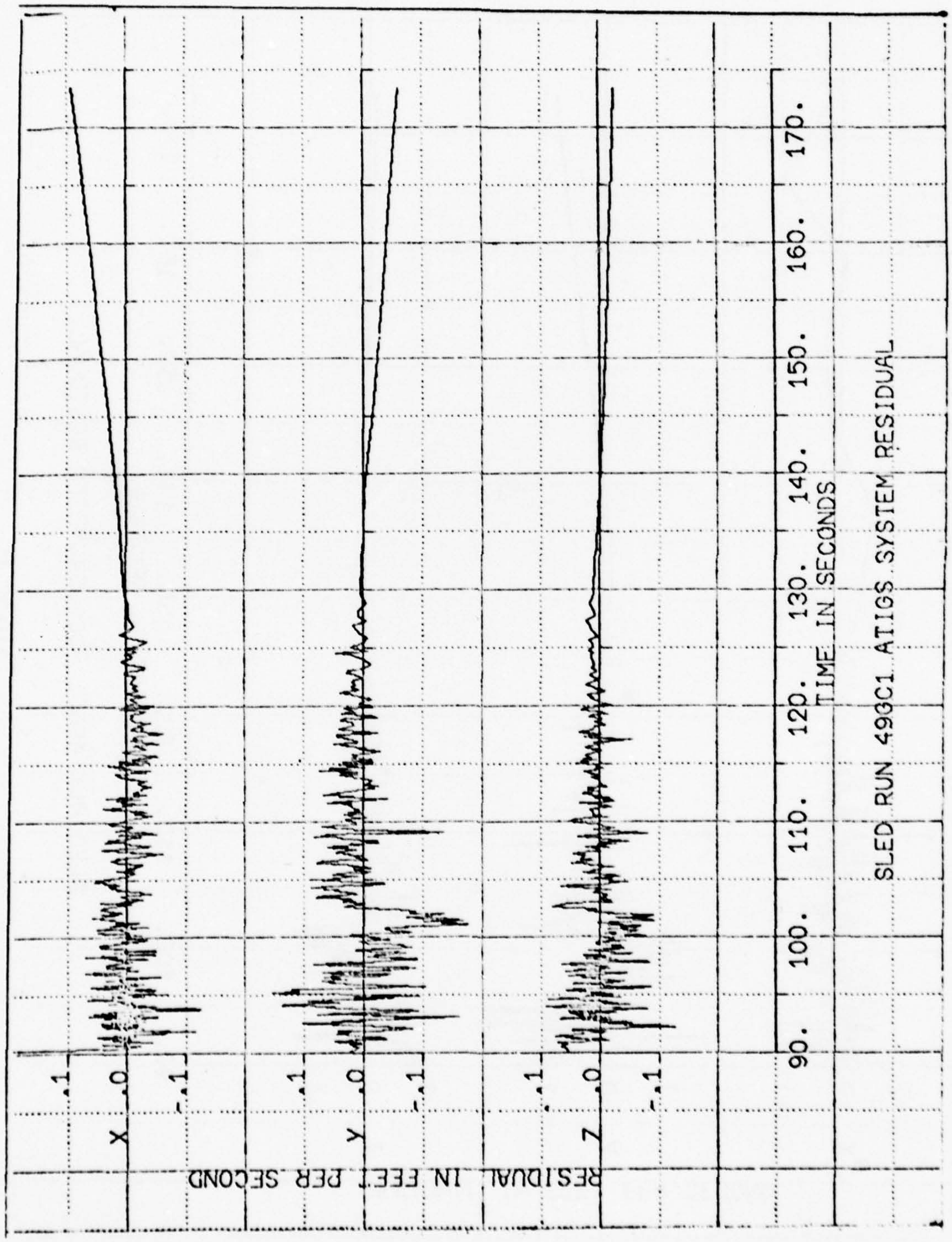
The system model coefficients are presented in Tables IV through VI. Coefficients are not presented for Run #2 due to the questionable gyro data. An effort was now extended to remove the remaining trends in the $\Delta V$ residual data by changing the model terms.

At this point in the modeling, the assumption was made that the trends observed in the accelerometer and system residual plots, for the y and z axes, were due only to the ATIGS accelerometers. Past experience has shown that accelerometers can be sensitive to cross-axis g-inputs. The ATIGS accelerometers were already compensated for scale factor unbalance; however, this was only for the respective normal g-input axis. Based upon a postulate of an asymmetrical cross-axis g-sensitivity, a new coordinate function was tried in the model. This new function had to account for the slope changes observed on the Y and Z-accelerometer residuals and system residuals. The integral of the absolute value of the down-track acceleration ($\int |A_x|$) was then derived. Linear regression analysis was repeated for the accelerometer (DV) errors in the y and z-axes using the new coordinate function, $\int |A_x|$. The accelerometer error had a residual improvement on both the y and z-residuals; the slopes were decreased.



SLED RUN 49901 ACCELEROMETER RESIDUAL

FIGURE 11




SLED RUN 493C1 ATIGS SYSTEM RESIDUAL

FIGURE 12

TABLE IV

X-SYSTEM MODEL COEFFICIENTS

| COORDINATE FUNCTION | COEFFICIENT UNITS | RUN #1 COEFFICIENTS | RUN #3 COEFFICIENTS | RUN #4 COEFFICIENTS |
|---|---|---|---|---|
| $\dot{A}$ | $K_{2i}(\mu Sec^2)$ | 26.7 | 37.2 | 2.84 |
| (Jerk Sensitivity) | $\sigma$ | 4.53 | 4.83 | 5.67 |
| A (Acceleration) | $K_{3i}(\mu Sec)$ | -21.9 | - 80.1 | - 39.6 |
| (Sensitivity) | $\sigma$ | 7.70 | 7.95 | 9.42 |
| $\int A^2$ (Second Order) | $K_{4i}$(ppm/g) | 6.76 | 8.58 | 12.1 |
| (Scale Factor) | $\sigma$ | .632 | .632 | .846 |
| V (Scale Factor) | $K_{5i}$(ppm) | -282. | -348. | -350. |
| | $\sigma$ | 7.22 | 7.05 | 8.75 |
| Residual Value | One Sigma $\sigma R$ | .0342 | .0347 | .0422 |

TABLE V

Y-SYSTEM MODEL COEFFICIENTS

| COORDINATE FUNCTION | COEFFICIENT UNITS | RUN #1 COEFFICIENTS | RUN #3 COEFFICIENTS | RUN #4 COEFFICIENTS |
|---|---|---|---|---|
| $\dot{A}$ | $K_{2i}$($\mu$Sec$^2$) | - 42.1 | -65.8 | -64.2 |
| (Jerk Sensitivity) | $\sigma$ | 7.76 | 11.1 | 11.0 |
| A | $K_{3i}$($\mu$Sec) | - 34.5 | 18.6 | -44.2 |
| (Acceleration Sensitivity) | $\sigma$ | 13.2 | 18.3 | 18.2 |
| $\int A^2$ | $K_{4i}$(arc-sec/g) | - 10.0 | - 9.35 | -10.1 |
| (Pallet Motion) | $\sigma$ | .223 | .296 | .307 |
| V | $K_{5i}$(arc-sec) | 162. | -16.7 | - 5.88 |
| (Misalignment | $\sigma$ | 2.55 | 10.8 | 3.50 |
| Residual Value | One Sigma $\sigma R$ | .059 | .080 | .082 |

TABLE VI

Z-SYSTEM MODEL COEFFICIENTS

| COORDINATE FUNCTION | COEFFICIENT UNITS | RUN #1 COEFFICIENTS | RUN #3 COEFFICIENTS | RUN #4 COEFFICIENTS |
|---|---|---|---|---|
| $\dot{A}$ | $K_{2i}$($\mu$Sec$^2$) | -25.2 | -56.5 | -17.5 |
| (Jerk Sensitivity) | $\sigma$ | 5.55 | 6.68 | 7.58 |
| A | $K_{3i}$($\mu$Sec) | 22.7 | 99.2 | 10.4 |
| (Acceleration Sensitivity) | $\sigma$ | 7.73 | 11.0 | 10.9 |
| $\int A^2$ | $K_{4i}$(Arc-Sec/g) | - 7.47 | -10.1 | - 7.39 |
| (Pallet Motion) | $\sigma$ | .131 | .178 | .184 |
| V | $K_{5i}$(Arc-Sec) | -55.9 | 21.7 | 4.37 |
| (Misalignment) | $\sigma$ | | 2.01 | 2.10 |
| Residual Value | One Sigma $\sigma R$ | .034 | .048 | .049 |

The residual functions from the new fit to the y and z DV's were significantly improved. Hence, the postulate of the new accelerometer error source appeared to be justified. Figure 13 shows the elimination of the slopes in in $DV_y$ and $DV_z$. The new coordinate function was then used for the system $\Delta V$'s instead of the $\int A^2$. The assumption here was that the gyros had no major scale factor errors and hence there existed no need for the $\int A^2$ function in the model.

In an effort to improve both the accelerometer and the system error description (for y and z only), the function $\int A^2$ was returned to the new model and two higher order asymmetric error terms, $|\dot{A}_x|$ and $|A_x|$ were used.

$$\Delta V_y \text{ or }_z = K_{0i} + K_{1i} t + K_{2i} \hat{\dot{A}}_x + K_{3i} \hat{A}_x + K_{4i} \int \hat{A}_x^2 + K_{5i} \hat{V}_x$$

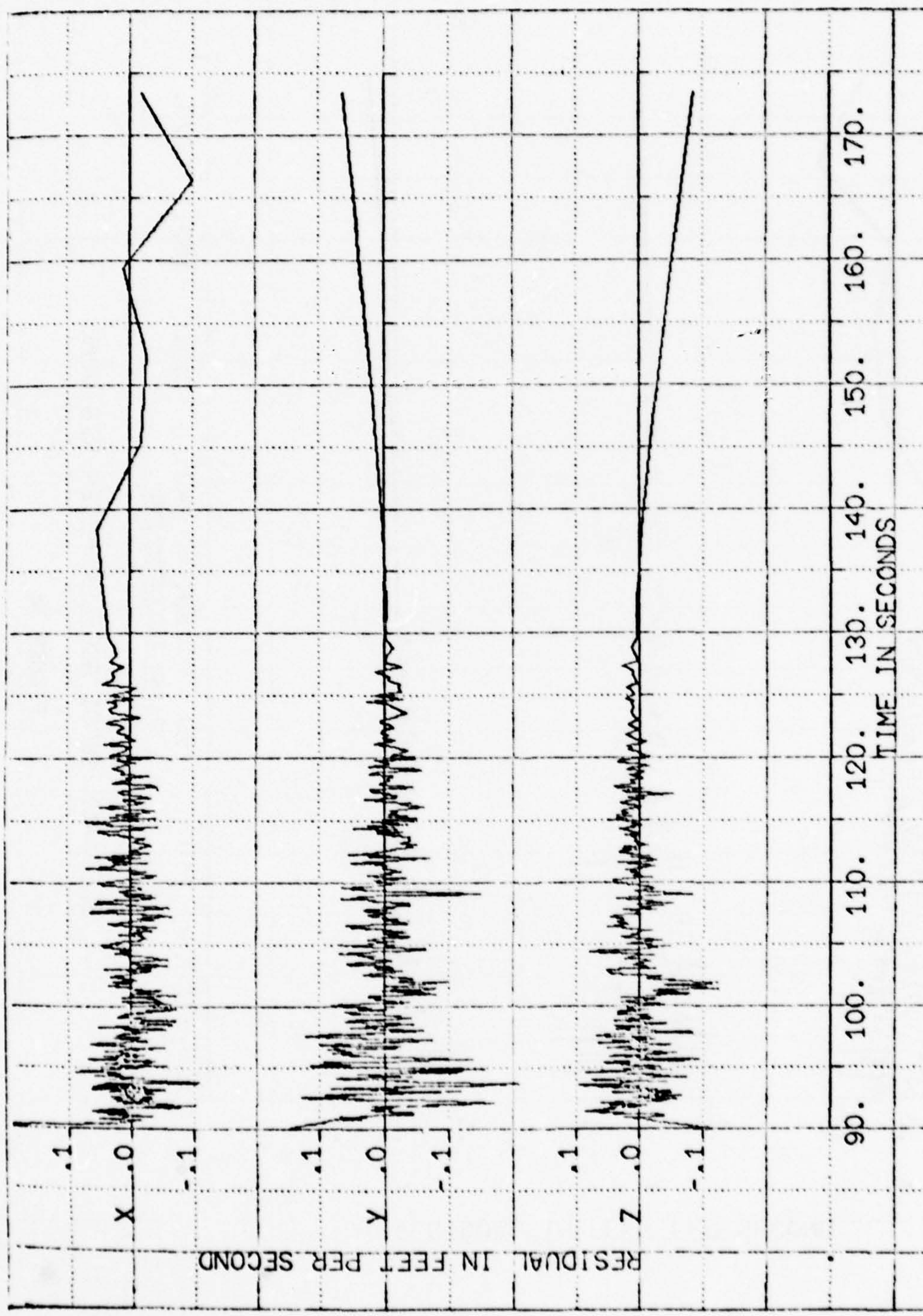
$$+ K_{6i} |\hat{\dot{A}}_x| + K_{7i} |\hat{A}_x| + K_{8i} \int |\hat{A}_x|$$

The regression results from the new fits to the $\Delta V_y$ and $\Delta V_z$ were significantly improved. Figures 14 and 15 show the enhanced removal of the slopes in both the $DV_y$, $DV_z$ residuals and the $\Delta V_y$, $\Delta V_z$ residuals.

In summary, the major coefficients for the new accelerometer nine-term model are found in Tables VII through IX. Also the one sigma values of the accelerometer residuals were lowest with this last model than they were for the other accelerometer model attempts. Tables X and XII contain the final model coefficients for the system $\Delta V_y$ and $\Delta V_z$ errors. As further justification of the model, it was observed that the new function $\int |A|$ was also necessary for proper description of the $\Delta V$'s obtained from centrifuge tests. The coefficient of the $\int |A|$ for the sled tests differed only by a factor of five or less from the centrifuge coefficient for $\int |A|$.

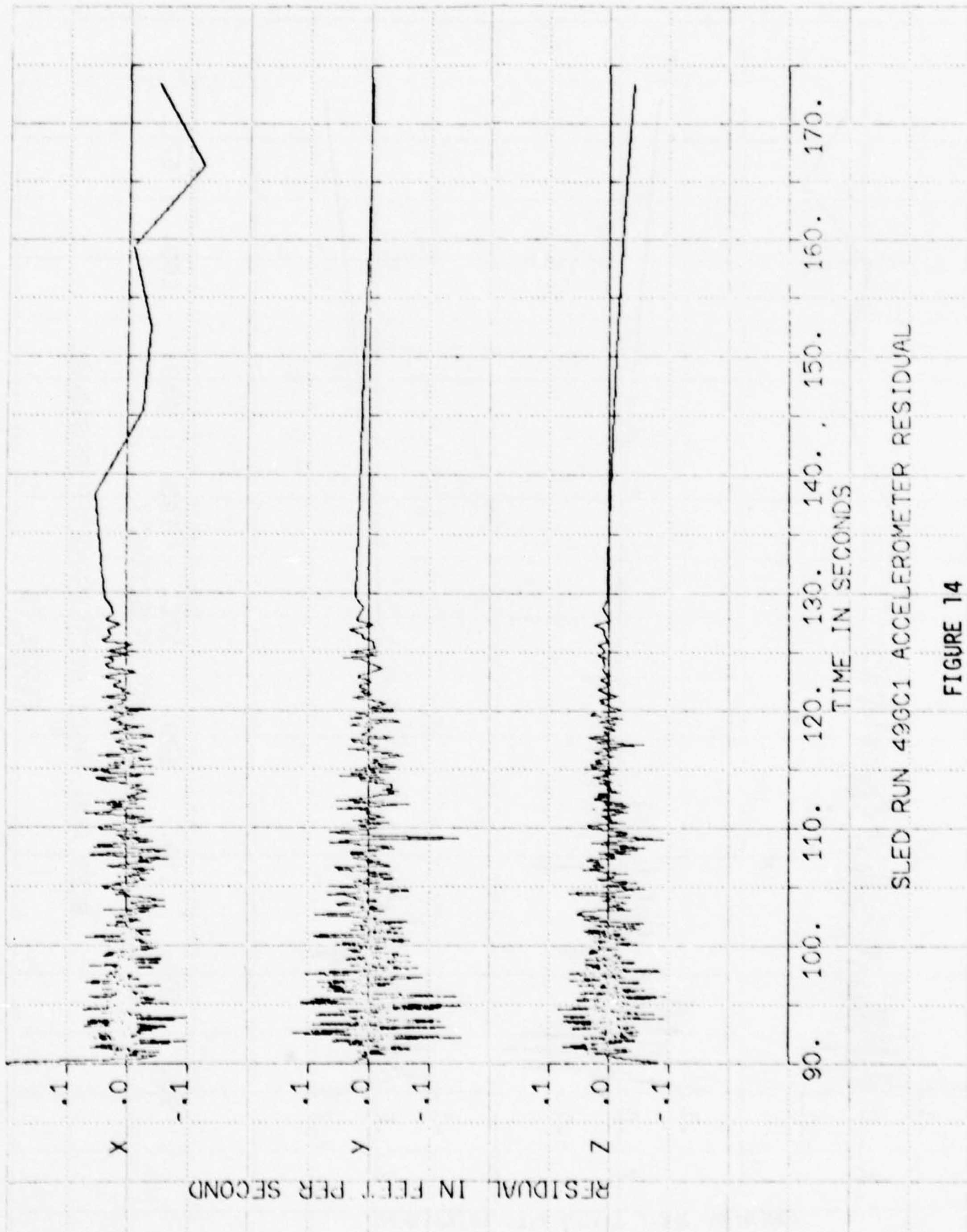
The regression analysis results, in spite of the various improvements, are admittedly not perfect. High correlation existed between two functions in the new model, making it difficult to separate gyro and accelerometer error sources. This correlation, namely between the function $\int |A|$ and $\int A^2$, is illustrated in Figure 16. When the residual contributions of these functions were examined separately, the values of each were often larger than the initial residual error. But because of the coefficient sign differences, the sum of the functions approximated the residual error. Figure 17, nevertheless, shows how well a summed value of the three coordinate functions, shown in Figure 16 (times their respective solved coefficients), approximates the system z-velocity error.

A recommendation for future tests would be to use a slightly different sled profile to help separate system errors so that the identification of more exotic functions would be possible. The sled profile should contain a longer period of acceleration, a higher velocity, and a longer interval of



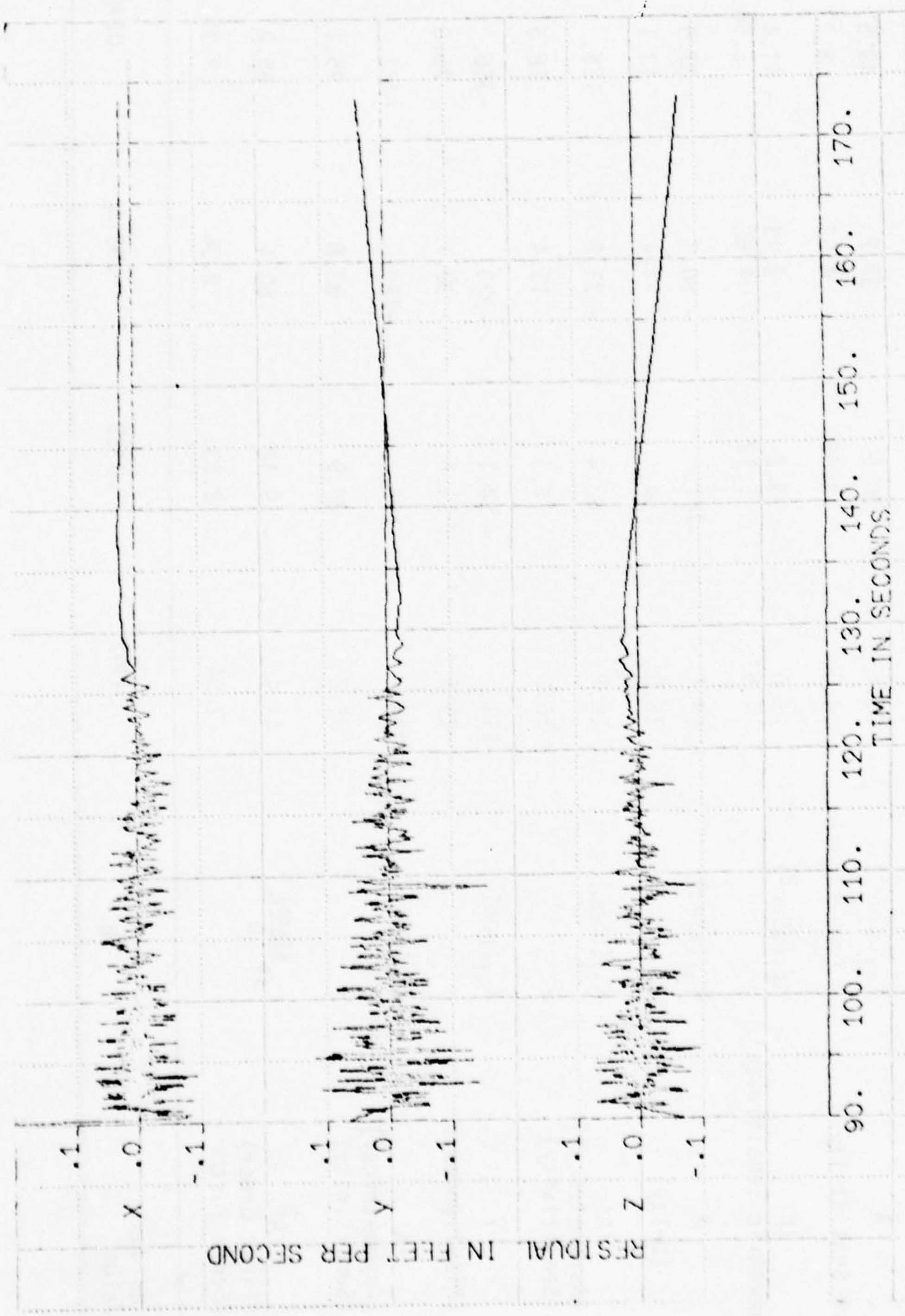

SLED RUN 49GC1 ACCELEROMETER RESIDUAL

FIGURE 13




SLED RUN 49GC1 ACCELEROMETER RESIDUAL

FIGURE 14




SLED RUN 49GC1 ATIGS SYSTEM RESIDUAL

FIGURE 15

TABLE VII

X-ACCELEROMETER MODEL COEFFICIENTS

| COORDINATE FUNCTION | COEFFICIENT UNITS | RUN #1 COEFFICIENTS | RUN #2 COEFFICIENTS | RUN #3 COEFFICIENTS | RUN #4 COEFFICIENTS |
|---|---|---|---|---|---|
| $\dot{A}$ | $K_{2i}(\mu Sec^2)$ | 38.6 | 30.5 | 37.2 | 49.5 |
| (Jerk Sensitivity | $\sigma$ (one sigma) | 4.36 | 4.68 | 4.67 | 5.27 |
| $\lvert\dot{A}\rvert$ | $K_{6i}(\mu Sec^2)$ | - 26.0 | - 33.2 | 2.93 | - 41.4 |
| (Asymmetric Sensitivity) | $\sigma$ | 4.57 | 5.12 | 4.85 | 5.56 |
| A | $K_{3i}(\mu Sec)$ | - 18.1 | -141. | - 56.3 | - 87.9 |
| (Delay) | $\sigma$ | 15.0 | 154. | 14.4 | 17.1 |
| $\lvert A\rvert$ (Asymmetrical) | $K_{7i}(\mu Sec)$ | 16.8 | 83.4 | - 21.8 | 116. |
| (Sensitivity) | $\sigma$ | 16.2 | 16.5 | 15.4 | 18.3 |
| V | $K_{5i}(ppm)$ | -211. | - 94.1 | -323. | -366. |
| (Misalignment) | $\sigma$ | 29.5 | 11.6 | 30.1 | 35.3 |
| $\int\lvert A\rvert$ (Asymmetrical) | $K_{8i}(ppm)$ | -338. | 196. | -483. | -482. |
| (Sensitivity) | $\sigma$ | 75.2 | 30.9 | 83.8 | 95.1 |
| $\int A^2$ (First Order) | $K_{4i}\frac{(ppm)}{g}$ | 43.9 | - 9.18 | 60.4 | 66.2 |
| (Scale Factor | $\sigma$ | 7.54 | 2.83 | 8.36 | 9.35 |
| Residual Value | $\sigma_R$ | .0307 | .0335 | .0315 | .0370 |

TABLE VIII

Y-ACCELEROMETER MODEL COEFFICIENTS

| COORDINATE FUNCTION | COEFFICIENT UNITS | RUN #1 COEFFICIENTS | RUN #2 COEFFICIENTS | RUN #3 COEFFICIENTS | RUN #4 COEFFICIENTS |
|---|---|---|---|---|---|
| $\dot{A}$ | $K_{2i}$ ($\mu Sec^2$) | - 29.4 | - 54.4 | - 25.9 | - 31.3 |
| (Jerk Sensitivity) | $\sigma$ (One sigma) | 6.97 | 6.79 | 6.49 | 7.78 |
| $\lvert \dot{A} \rvert$ (Asymmetrical) | $K_{6i}$ ($\mu Sec^2$) | - 91.1 | -101. | - 40.6 | - 89.9 |
| (Cross-Axis Sensitivity) | $\sigma$ | 7.30 | 7.42 | 6.75 | 8.19 |
| A | $K_{3i}$ ( Sec) | 34.1 | 54.9 | 102. | 99.4 |
| (Acceleration Sensitivity) | $\sigma$ | 23.9 | 22.4 | 20.0 | 25.2 |
| $\lvert A \rvert$ (Asymmetrical | $K_{7i}$ ( Sec) | -106. | 172. | -576. | - 53.8 |
| (Cross-Axis Sensitivity) | $\sigma$ | 25.9 | 22.4 | 20.0 | 26.9 |
| V | $K_{5i}$ (Arc-Sec) | 176. | 130. | -178. | -224. |
| (Misalignment) | $\sigma$ | 9.73 | 3.47 | 8.63 | 10.7 |
| $\int \lvert A \rvert$ (Asymmetrical) | $K_{8i}$ $\frac{\text{(Parts Y)}}{(10^6 \text{ Parts X})}$ | 967. | 426. | 31.4 | 232. |
| (Cross-Axis Sensitivity) | $\sigma$ | 120. | 44.9 | 11.6 | 140. |
| $\int A^2$ | $K_{4i}$ $\frac{\text{(Arc-Sec)}}{g}$ | - 11.76 | 1.02 | 24.6 | 6.21 |
| (Pallet Motion) | $\sigma$ | 2.49 | .847 | 2.40 | 2.84 |
| Residual Value | $\sigma_R$ | .0491 | .0485 | .0438 | .046 |

TABLE IX

Z-ACCELEROMETER MODEL COEFFICIENTS

| COORDINATE FUNCTION | COEFFICIENT UNITS | RUN #1 COEFFICIENTS | RUN #2 COEFFICIENTS | RUN #3 COEFFICIENTS | RUN #4 COEFFICIENTS |
|---|---|---|---|---|---|
| $\dot{A}$ | $K_{2i}$ ($\mu Sec^2$) | 3.68 | - 58.2 | - 31.7 | 20.1 |
| (Jerk Sensitivity) | $\sigma$ (One Sigma) | 4.01 | 7.37 | 4.85 | 4.82 |
| $\lvert\dot{A}\rvert$ | $K_{6i}$ ($\mu Sec^2$) | 20.6 | 5.57 | 7.69 | 19.0 |
| (Cross-Axis Sensitivity) | $\sigma$ | 4.20 | 8.05 | 5.04 | 5.08 |
| A | $K_{3i}$ ($\mu Sec$) | -139. | -163. | 107. | -136. |
| (Acceleration Sensitivity) | $\sigma$ | 13.8 | 24.3 | 15.0 | 15.6 |
| $\lvert A\rvert$ (Asymmetrical) | $K_{7i}$ ($\mu Sec$) | -235. | -311. | -226. | -301. |
| (Cross-Axis Sensitivity) | $\sigma$ | 14.9 | 26.0 | 16.1 | 16.7 |
| V | $K_{5i}$ (Arc-Sec) | -165. | 128. | 31.5 | 69.5 |
| (Misalignment) | $\sigma$ | 5.60 | 3.77 | 6.45 | 6.66 |
| $\int\lvert A\rvert$ (Asymmetrical) | $K_{8i}$ $\frac{\text{(Parts Z)}}{(10^6 \text{ Parts X})}$ | -934. | 1385. | -325. | -904. |
| (Cross-Axis Sensitivity) | $\sigma$ | 69.3 | 48.7 | 87.1 | 86.9 |
| $\int A^2$ | $K_{4i}$ $\frac{\text{(Arc-Sec)}}{g}$ | 57.4 | 6.13 | 33.0 | 52.6 |
| (Pallet Motion) | $\sigma$ | 1.43 | .919 | 1.79 | 1.76 |
| Residual Value | $\sigma_R$ | .0283 | .0527 | .0327 | .0339 |

TABLE X

X SYSTEM MODEL COEFFICIENTS

| COORDINATE FUNCTION | COEFFICIENT UNITS | RUN #1 COEFFICIENTS | RUN #3 COEFFICIENTS | RUN #4 COEFFICIENTS |
|---|---|---|---|---|
| $\dot{A}$ | $K_{2i}$ ($\mu$Sec$^2$) | 37.3 | 45.4 | 37.2 |
| (Jerk Sensitivity) | $\sigma$ (One Sigma) | 4.38 | 4.85 | 5.19 |
| $\lvert\dot{A}\rvert$ (Asymmetrical) | $K_{6i}$ ($\mu$Sec$^2$) | - 19.1 | 19.1 | 42.0 |
| (Sensitivity) | $\sigma$ | 4.59 | 5.03 | 5.47 |
| A | $K_{3i}$ ($\mu$Sec) | - 45.5 | - 77.1 | -117. |
| (Delay) | $\sigma$ | 15.1 | 14.9 | 16.8 |
| $\lvert A\rvert$ (Asymmetrical) | $K_{7i}$ ($\mu$Sec) | 62.6 | 23.3 | 159. |
| (Sensitivity) | $\sigma$ | 16.3 | 16.0 | 18.0 |
| V | $K_{5i}$ (ppm) | -551. | -606. | -619. |
| (Misalignment) | $\sigma$ | 29.6 | 31.4 | 34.7 |
| $\int\lvert A\rvert$ (Asymmetrical) | $K_{8i}$ $\frac{(\text{Parts X})}{(10^6 \text{ Parts X})}$ | -790. | -840. | -836. |
| (Sensitivity) | $\sigma$ | 75.6 | 87.0 | 93.6 |
| $\int A^2$ (First Order) | $K_{4i}$ $\frac{(\text{ppm})}{g}$ | 81.8 | 88.0 | 89.3 |
| (Scale Factor) | $\sigma$ | 7.57 | 8.68 | 9.20 |
| Residual Value | $\sigma_R$ | .0309 | .0327 | .0365 |

TABLE XII

Z SYSTEM MODEL COEFFICIENTS

| COORDINATE FUNCTION | COEFFICIENT UNITS | RUN #1 COEFFICIENTS | RUN #3 COEFFICIENTS | RUN #4 COEFFICIENTS |
|---|---|---|---|---|
| $\dot{A}$ | $K_{2i}$ ($\mu$Sec$^2$) | .625 | - 25.3 | 21.4 |
| (Jerk Sensitivity) | $\sigma$ (One Sigma) | 4.02 | 4.65 | 4.53 |
| $\lvert\dot{A}\rvert$ (Asymmetrical) | $K_{6i}$ ($\mu$Sec$^2$) | - 2.62 | 1.12 | 1.56 |
| (Cross-Axis Sensitivity | $\sigma$ | 4.21 | 4.23 | 4.77 |
| A | $K_{3i}$ ($\mu$Sec) | 45.6 | 121. | - 5.55 |
| (Acceleration Sensitivity) | $\sigma$ | 13.8 | 14.3 | 14.7 |
| $\lvert A\rvert$ (Asymmetrical) | $K_{7i}$ ($\mu$Sec) | -134. | -260. | -214. |
| (Cross-Axis Sensitivity) | $\sigma$ | 14.9 | 15.4 | 15.7 |
| V | $K_{5i}$ (Arc-Sec) | -129. | - 29.9 | - 50.1 |
| (Misalignment) | $\sigma$ | 5.60 | 6.18 | 6.25 |
| $\int\lvert A\rvert$ (Asymmetrical) | $K_{8i}$ $\frac{\text{(Parts Z)}}{(10^6 \text{ Parts X)}}$ | -746. | -214. | -777. |
| (Cross-Axis Sensitivity) | $\sigma$ | 69.3 | 83.5 | 81.6 |
| $\int A^2$ | $K_{4i}$ $\frac{\text{(Arc-Sec)}}{g}$ | 9.92 | .948 | 13.0 |
| (Pallet Motion) | $\sigma$ | 1.43 | 1.72 | 1.66 |
| Residual Value | $\sigma_R$ | .0283 | .0314 | .0318 |

TABLE XI

Y SYSTEM MODEL COEFFICIENTS

| COORDINATE FUNCTION | COEFFICIENT UNITS | RUN #1 COEFFICIENTS | RUN #3 COEFFICIENTS | RUN #4 COEFFICIENTS |
|---|---|---|---|---|
| $\dot{A}$ | $K_{2i}$ ($\mu$Sec$^2$) | - 26.1 | - 18.5 | - 20.4 |
| (Jerk Sensitivity) | $\sigma$ (One Sigma) | 6.52 | 6.10 | 7.43 |
| $\|A\|$ (Asymmetrical) | $K_{6i}$ ($\mu$Sec$^2$) | - 71.7 | - 57.4 | - 76.2 |
| (Cross-Axis Sensitivity) | $\sigma$ | 6.83 | 6.34 | 7.82 |
| A | $K_{3i}$ ($\mu$Sec) | 121. | 102. | - 79.8 |
| (Acceleration Sensitivity) | $\sigma$ | 22.4 | 18.8 | 24.1 |
| $\|A\|$ (Asymmetrical) | $K_{7i}$ ($\mu$Sec) | -322. | -511. | -307. |
| (Cross-Axis Sensitivity) | $\sigma$ | 24.2 | 20.2 | 25.7 |
| V | $K_{5i}$ (Arc-Sec) | 199. | - 47.0 | - 33.5 |
| (Misalignment) | $\sigma$ | 9.10 | 8.11 | 10.2 |
| $\int\|A\|$ (Asymmetrical | $K_{8i}$ $\frac{(\text{Parts Y})}{(10^6 \text{ Parts X})}$ | 764. | 493. | 491. |
| (Cross-Axis Sensitivity) | $\sigma$ | 113. | 110. | 134. |
| $\int A^2$ | $K_{4i}$ $\frac{(\text{Arc-Sec})}{g}$ | - 22.5 | - 10.8 | - 11.9 |
| (Pallet Motion) | $\sigma$ | 2.32 | 2.25 | 2.72 |
| Residual Value | $\sigma_R$ | .046 | .0412 | .0522 |

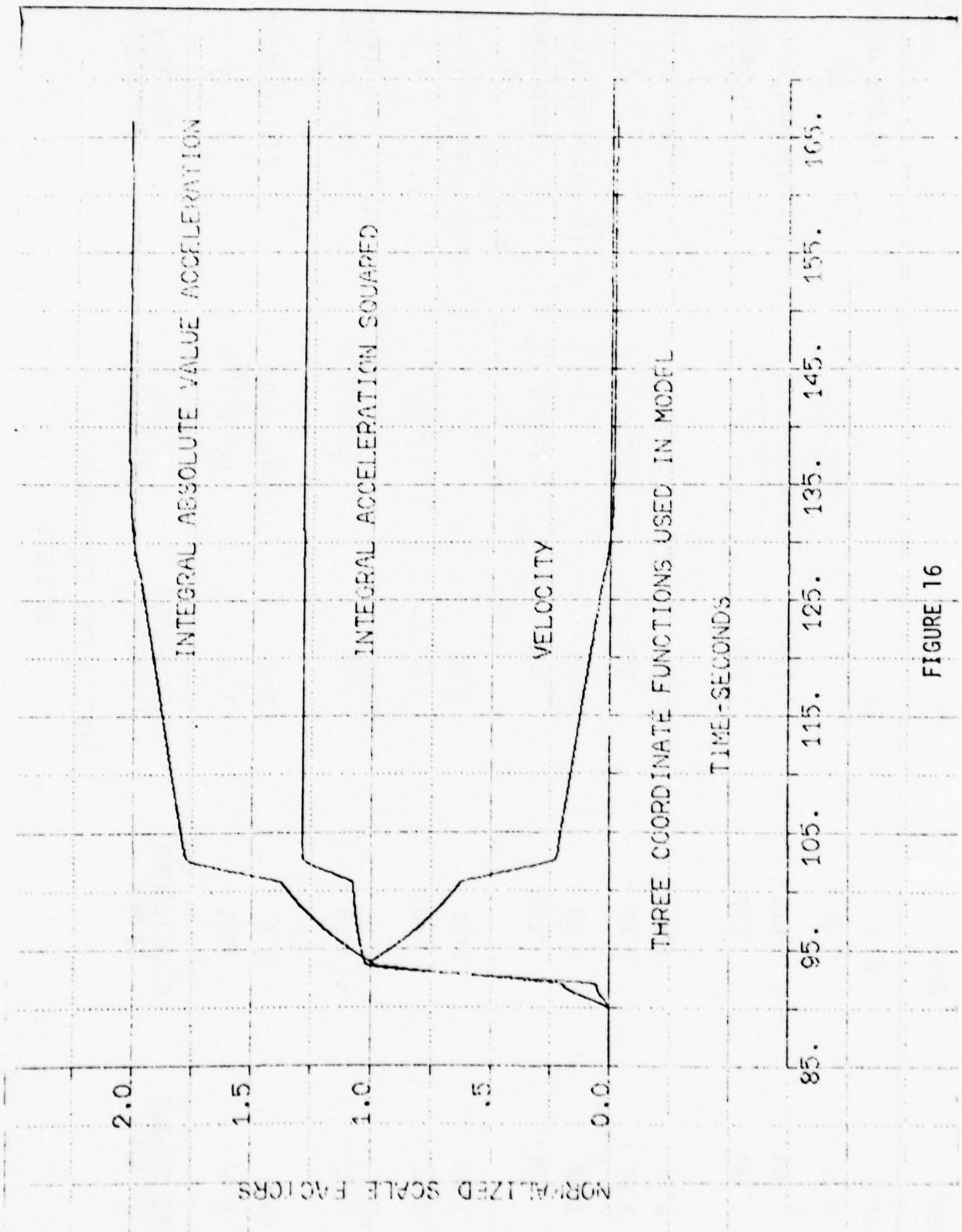
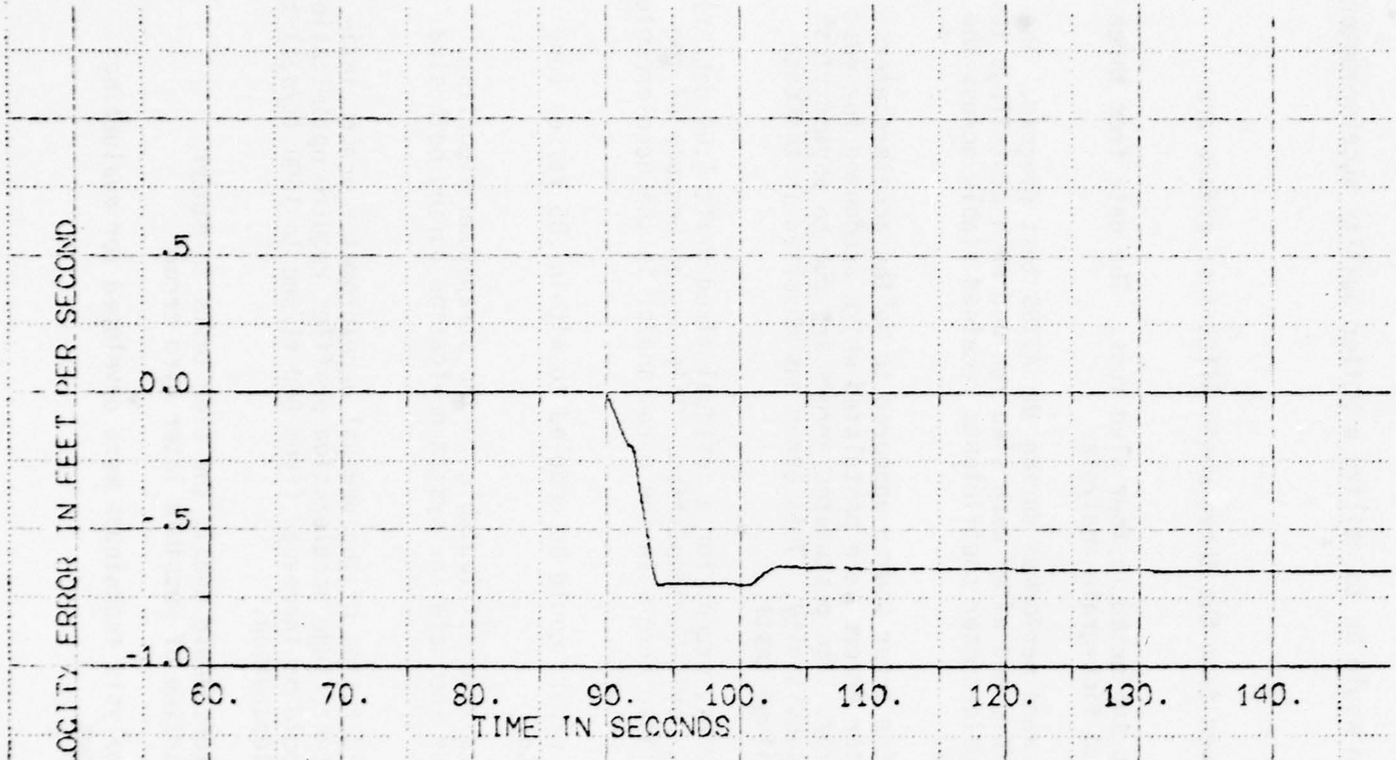

INTEGRAL ABSOLUTE VALUE ACCELERATION
INTEGRAL ACCELERATION SQUARED
VELOCITY
THREE COORDINATE FUNCTIONS USED IN MODEL
TIME-SECONDS
NORMALIZED SCALE FACTORS
2.0
1.5
1.0
.5
0.0
85.
95.
105.
115.
125.
135.
145.
155.
165.

FIGURE 16




CONTRIBUTION OF 3 COORDINATE FUNCTIONS

TO SYSTEM Z VELOCITY ERROR FIT

FIGURE 17

deceleration. This would allow greater separation of the coordinate functions during linear regression analysis and may result in a better model of accelerometer and gyro performance.

A further suggestion would be to utilize a better quality accelerometer in the system.

## 5. CONCLUSIONS

The conclusions derived from the three-month ATIGS test effort are summarized below.

5.1 The ATIGS system was subjected to four sled runs. The data from three sled runs was submitted to fine-grain analysis.

5.2 Twelve calibrations were performed during the ATIGS test program. The system was calibrated before and after each sled run and each centrifuge test series. The gyro and accelerometer coefficients remained stable across the dynamic test environments.

5.3 The predominant system error source appeared to be the accelerometers. Three unusual accelerometer errors were postulated which accounted for most of the observed ATIGS error. The postulated errors are due to asymmetrical cross-axis acceleration sensitivity. This error was observed in the data from both sled and centrifuge tests.

5.4 No specific gyro errors, except for a residual fixed drift (.04 deg/hr), based on centrifuge data, could be identified. This may be because of the existence of as yet undefined errors in the gyros and/or in the accelerometers (which affect the system output).

5.5 The system velocity errors could be modeled to within .05 ft/sec (one sigma) from sled test data.

5.6 No significant errors were attributable to the strap-down algorithm. The 100 Hz update rate was adequate for system navigation during both sled and centrifuge tests.

5.7 In retrospect, consideration of the unusual accelerometer errors indicates that the sled and centrifuge acceleration profiles require optimization. Sled maximum velocity should be increased (from 860 ft/sec to 1600 ft/sec) to aid in model error-term separation.

5.8 Improved accelerometers would enable the sled tests to center specifically on identification of possible laser gyro errors.

5.9 Improved test and analysis techniques were developed for evaluating strap-down guidance systems.

## REFERENCES

1. Morgan, A., "Attachment IV Flight Program Requirements Document (Preliminary)", Honeywell, Inc., Aerospace Division, St. Petersburg, Florida, 23 May 1973 in support of ATIGS Program.

2. Ingold, N., Smith, Capt W., "Rocket Sled Test Evaluation of the Lance Gyro by Strap-Down Analysis Techniques", Sixth Guidance Test Symposium Proceedings, AFSWC TR-72-73, Volume I.

3. Cosentino, D., Walker, D., "Rocket Sled and Centrifuge Tests of the Advanced Tactical Inertial Navigation Systems (ATIGS)", Final Report, ADTC TR-77-7.

ATIGS

ADVANCED TACTICAL INERTIAL

NAVIGATION SYSTEM

SLED TESTS

DONALD F. WALKER

CENTRAL INERTIAL GUIDANCE TEST FACILITY
HOLLOMAN AFB, NEW MEXICO

## SLED TEST DESCRIPTION

- PHASE I
  ENVIRONMENTAL SLED RUNS
- PHASE II
  SYSTEM INTEGRATION TO TEST SITE
- PHASE III
  HIGH SPEED SLED RUNS

## SLED RUN PROFILE

- PROPULSION

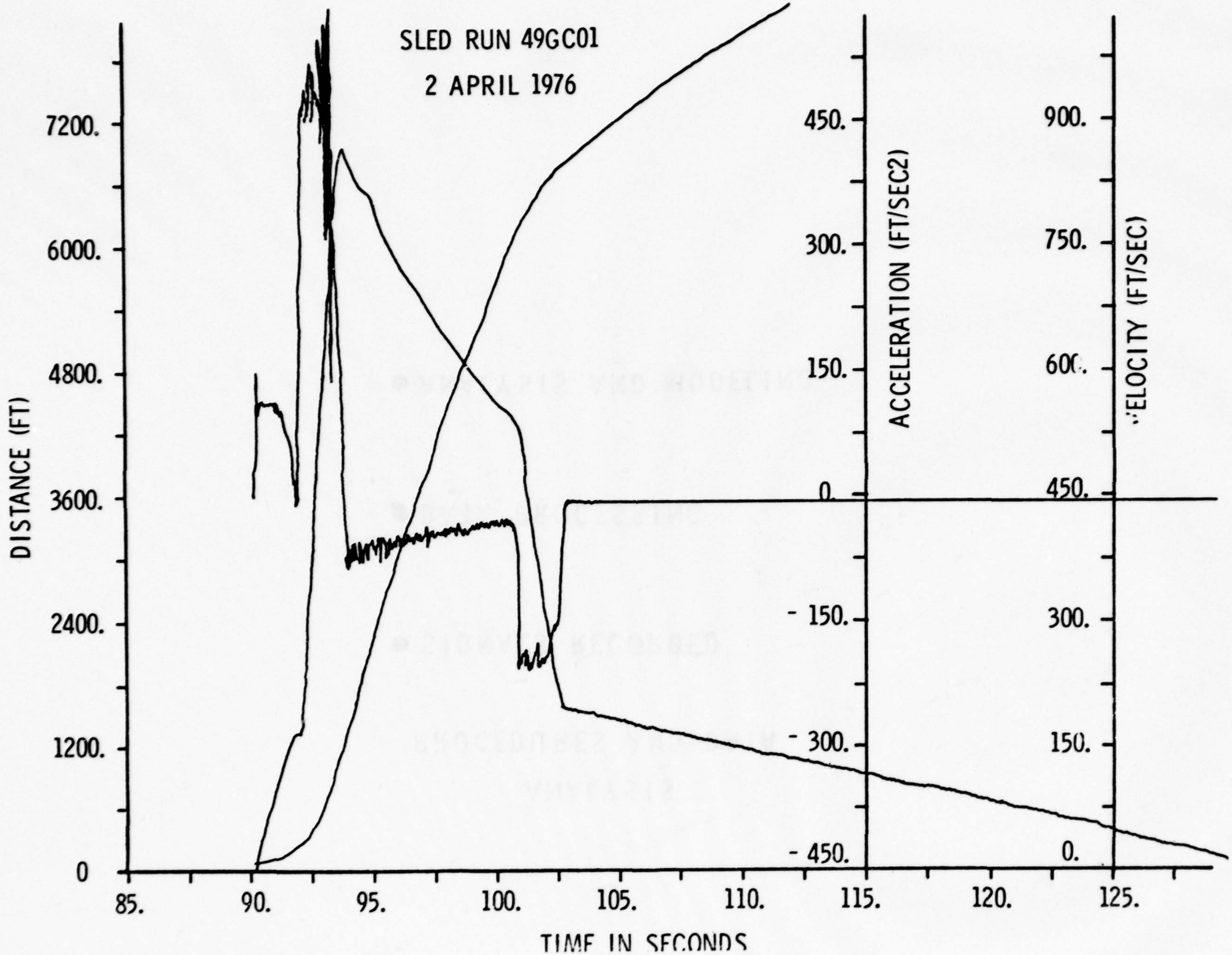
  5 LITTLE JOHN ROCKETS

- ENVIRONMENT

  ACCELERATION - 15.0 G'S

  VELOCITY - 865. F/S

  DECELERATION - -6.7 G'S


SLED RUN 49GC01
2 APRIL 1976
DISTANCE (FT)
7200.
6000.
4800.
3600.
2400.
1200.
0
ACCELERATION (FT/SEC2)
450.
300.
150.
0
- 150.
- 300.
- 450.
VELOCITY (FT/SEC)
900.
750.
600.
450.
300.
150.
0.
85.
90.
95.
100.
105.
110.
115.
120.
125.
TIME IN SECONDS

## ANALYSIS
## PROCEDURES AND DATA

- SIGNALS RECORDED
- DATA PROCESSING
- ANALYSIS AND MODELING

## SLED RECORDER SIGNALS

- ATIGS FLIGHT COMPUTER OUTPUTS
  - PULSE CODE MODULATED
  - DATA RATE 10 HZ.
- SENSOR DATA
  - GYROS - ANGLE INCREMENTS
  - ACCELS. - VELOCITY INCREMENTS
  - DATA RATE SEVERAL KHZS.
- SPACE TIME REFERENCE DATA
  - PRECISE SLED POSITION
  - ACCURATE TIME $<$ 1 MICROSECOND

## DATA PROCESSING

- GIC FACILITY (GENERAL INPUT CONVERTER)

  A/D CONVERSION

  48 BIT COMPUTER WORDS

- CDC 7600 COMPUTER

  50KB DATA LINK

  SENSOR DATA REDUCED
  STRAPPED-DOWN ALGORITHM

  SPACE TIME DATA REDUCED
  REFERENCE FRAME

## ANALYSIS PROCEDURES

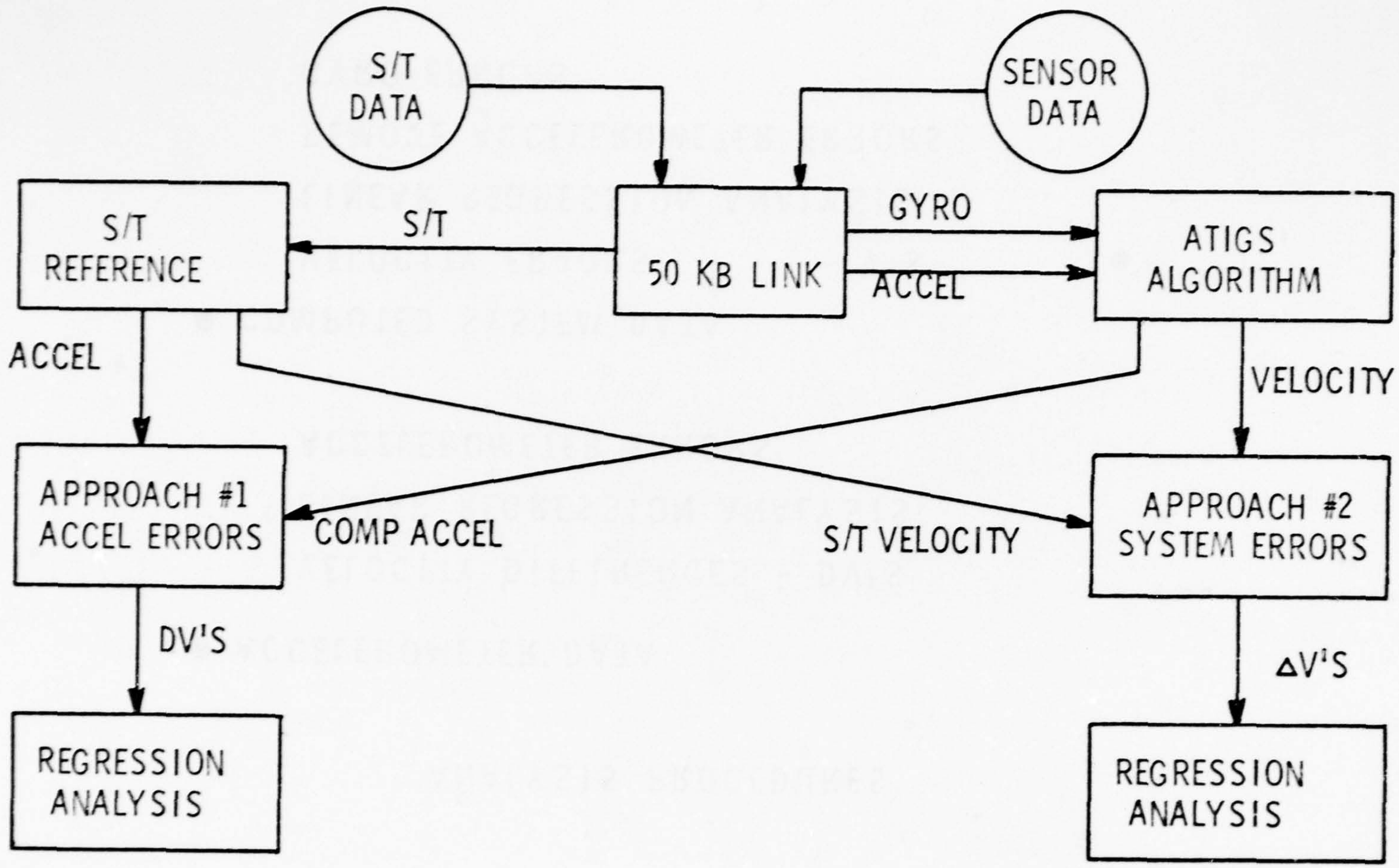
- ACCELEROMETER DATA

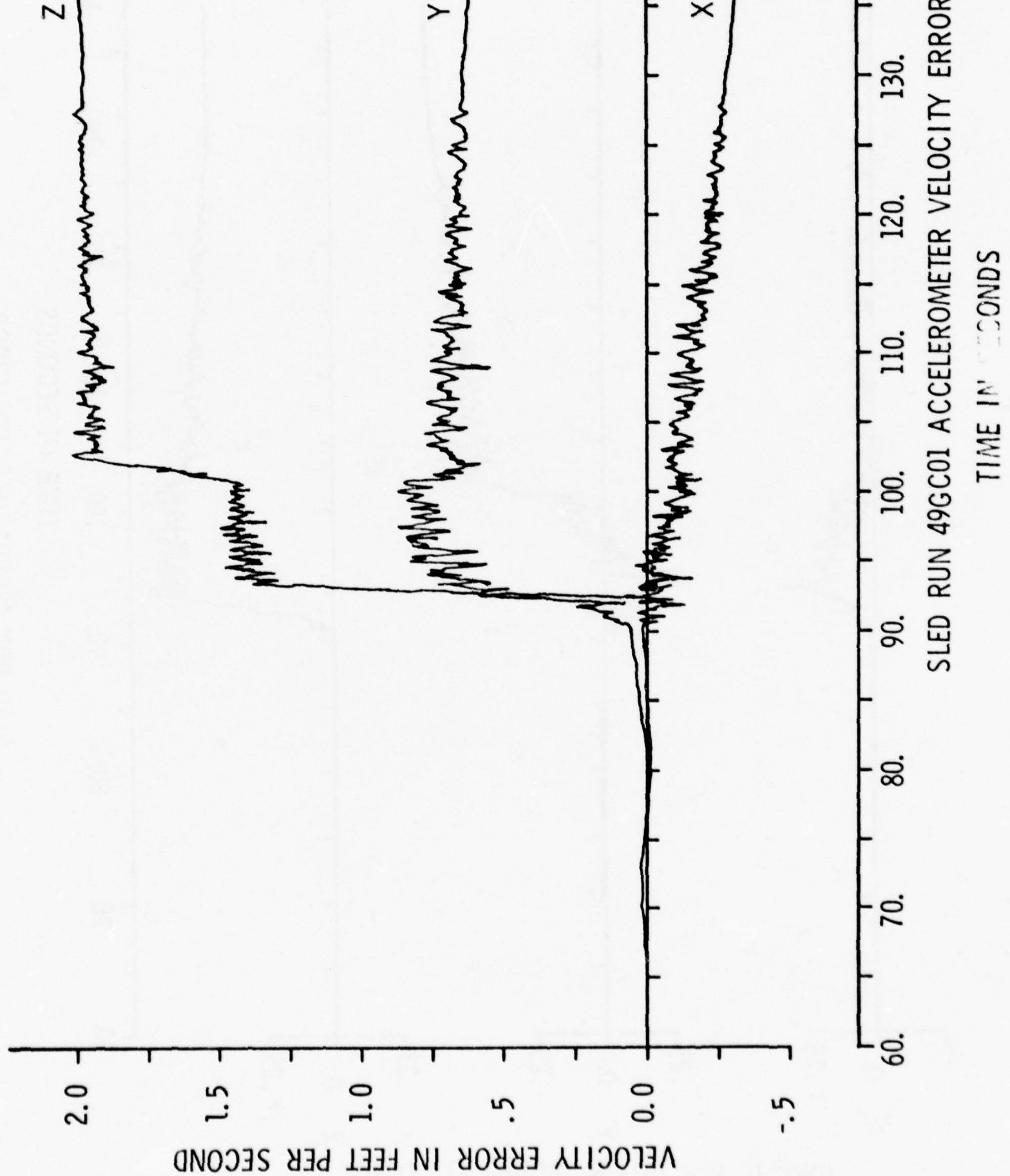
  VELOCITY DIFFERENCES - DV'S
  LINEAR REGRESSION ANALYSIS
  ACCELEROMETER ERRORS

- COMPUTED SYSTEM DATA

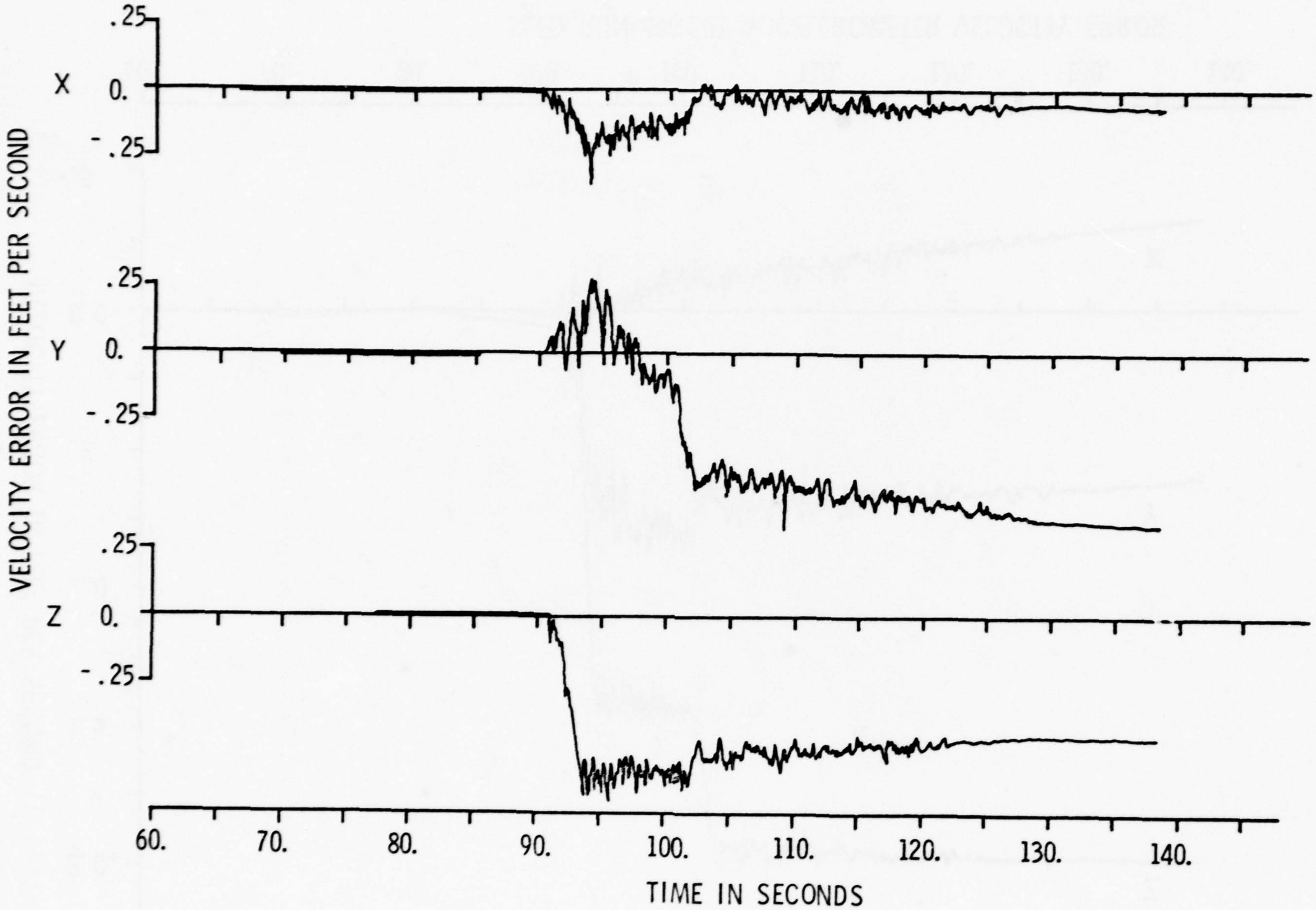
  VELOCITY ERRORS - V'S
  LINEAR REGRESSION ANALYSIS
  REMOVE ACCELEROMETER ERRORS
  GYRO ERRORS

## ANALYSIS OF ATIGS






SLED RUN 49GC01 ACCELEROMETER VELOCITY ERROR




SLED RUN 49GC01 VEL[illegible]ITY ERROR

ACCELEROMETER ERRORS

- X DV ERROR SMALL
- Y, Z DV ERRORS LARGE

DYNAMIC $\theta_Z = KA_X$

ERROR $A_X = \theta A_X = KA_X^2$

ERROR $V_Z = K \int A_X^2 \, dt$

## INITIAL ERROR MODEL

$$\text{ERROR} = K_{01} + K_{11} T + K_{21} A_x + K_{31} \dot{A}_x + K_{41} \int A_x^2 + K_{51} V_x$$

$K_{01}$ = OFFSET

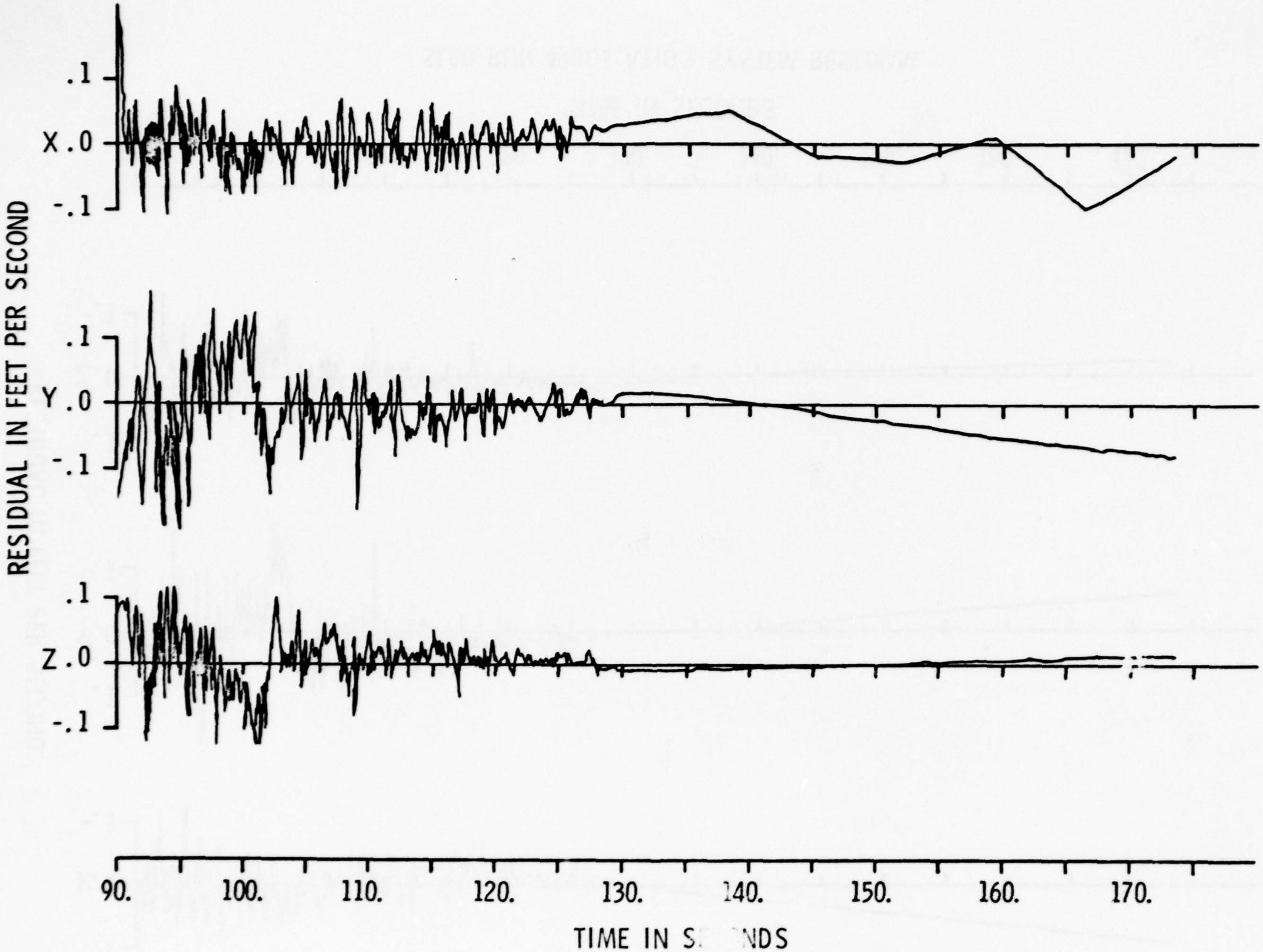
$K_{11}$ = BIAS

$K_{21}$ = ACCELERATION SENSITIVITY

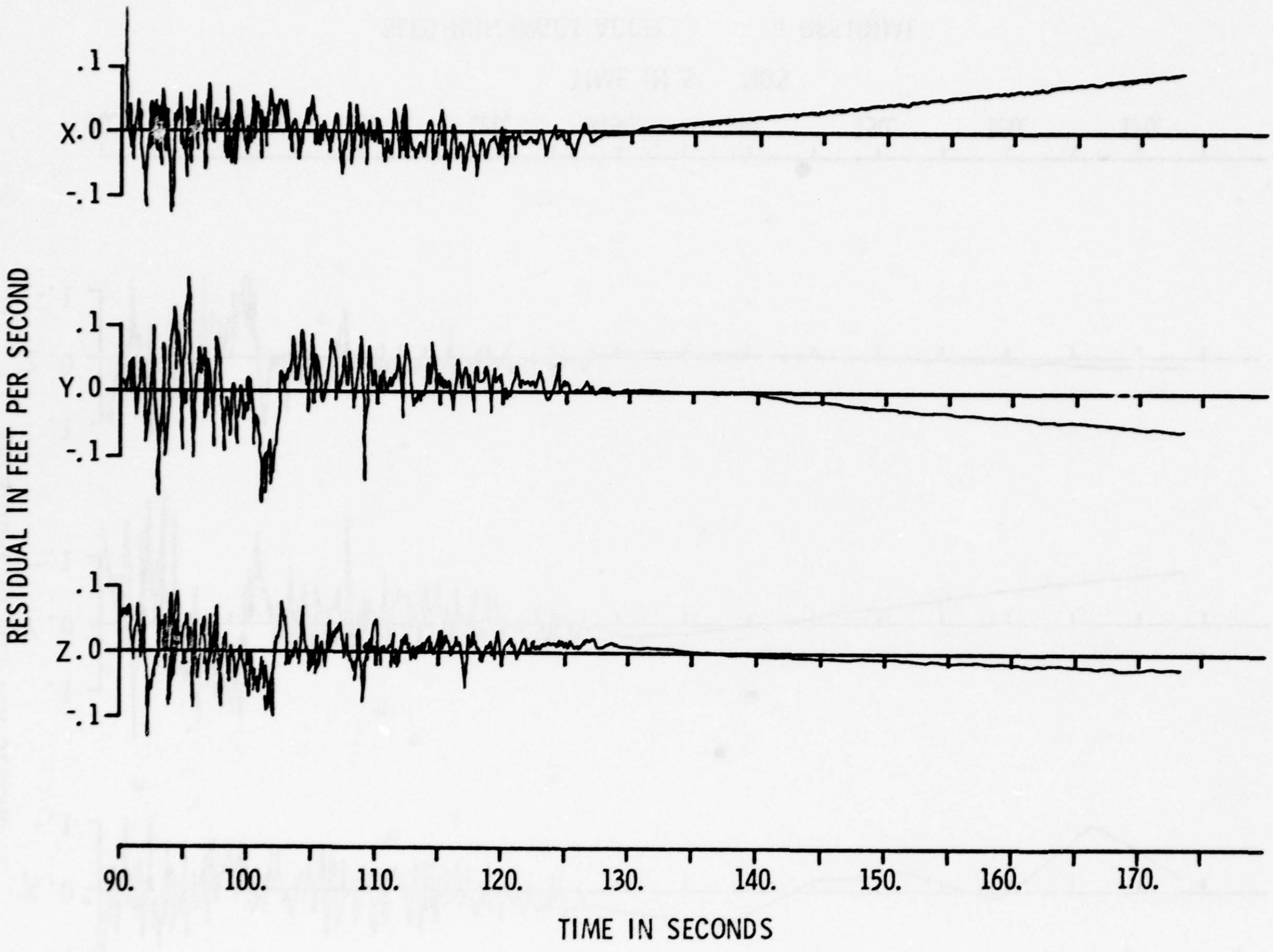
$K_{31}$ = JERK SENSITIVITY

$K_{41}$ = X S.F. NONLIN.: Y, Z PALLET MOTION

$K_{51}$ = X SCALE FACTOR: Y, Z MISALIGNMENT




SLED RUN 49GC1 ACCEL... R RESIDUAL




SLED RUN 49GC1 ATIGS SYSTEM RESIDUAL

# RESIDUAL ERRORS

- EXAMINATION OF RESIDUALS

  INITIAL MODEL INCOMPLETE

  UNDEFINED FUNCTIONS

  SIMILAR RESIDUALS
  ACCELEROMETER SYSTEM

- CONCLUSION BASED ON RESULTS

  ACCELEROMETER MODEL INCOMPLETE

  Y AND Z CROSS-AXIS SENSITIVITY

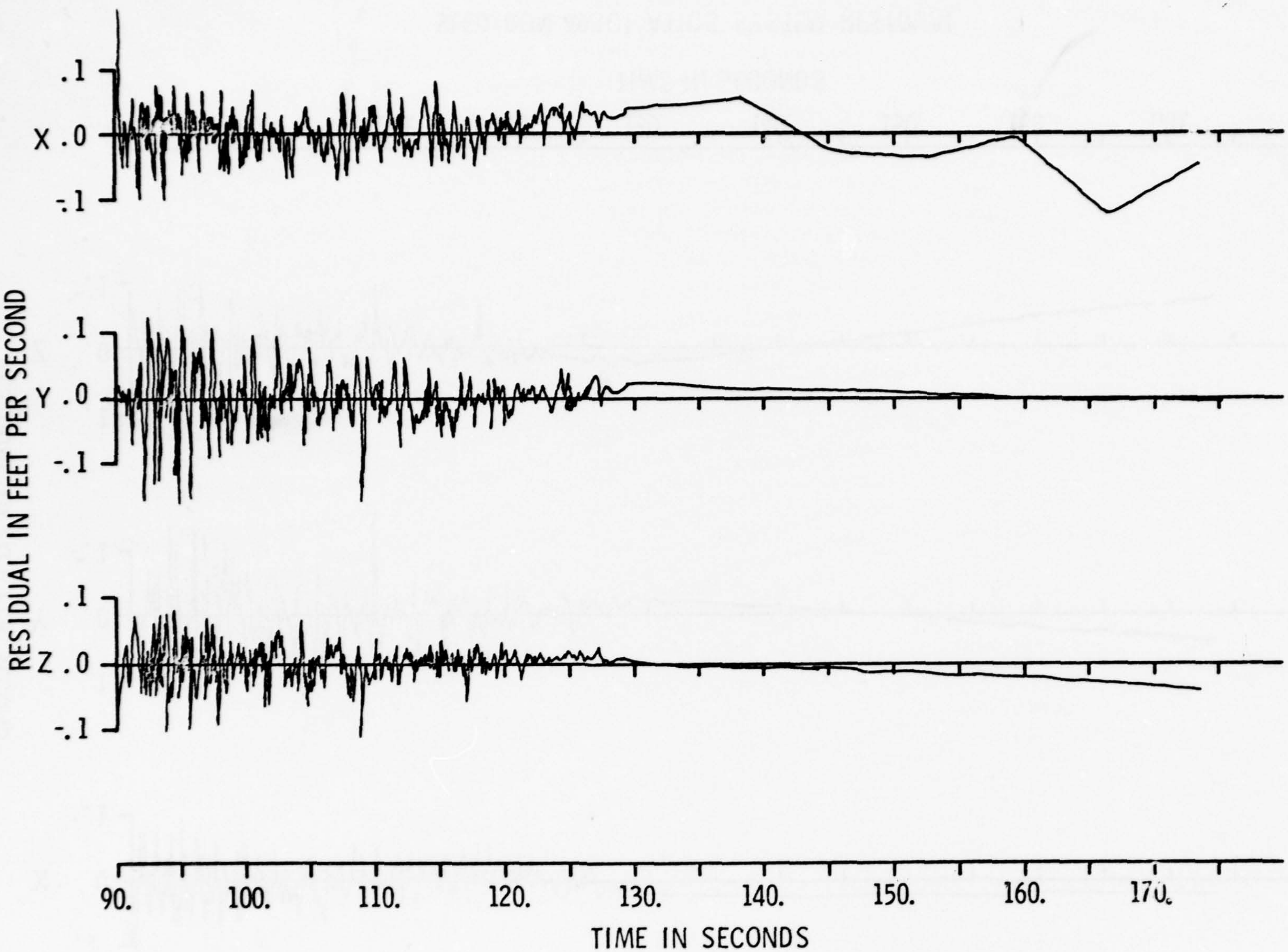
## NEW MODEL TERMS

- TERMS ARE: $\left|\dot{A}_x\right| \quad \left|A_x\right| \quad \int\left|A_x\right|\,dt$

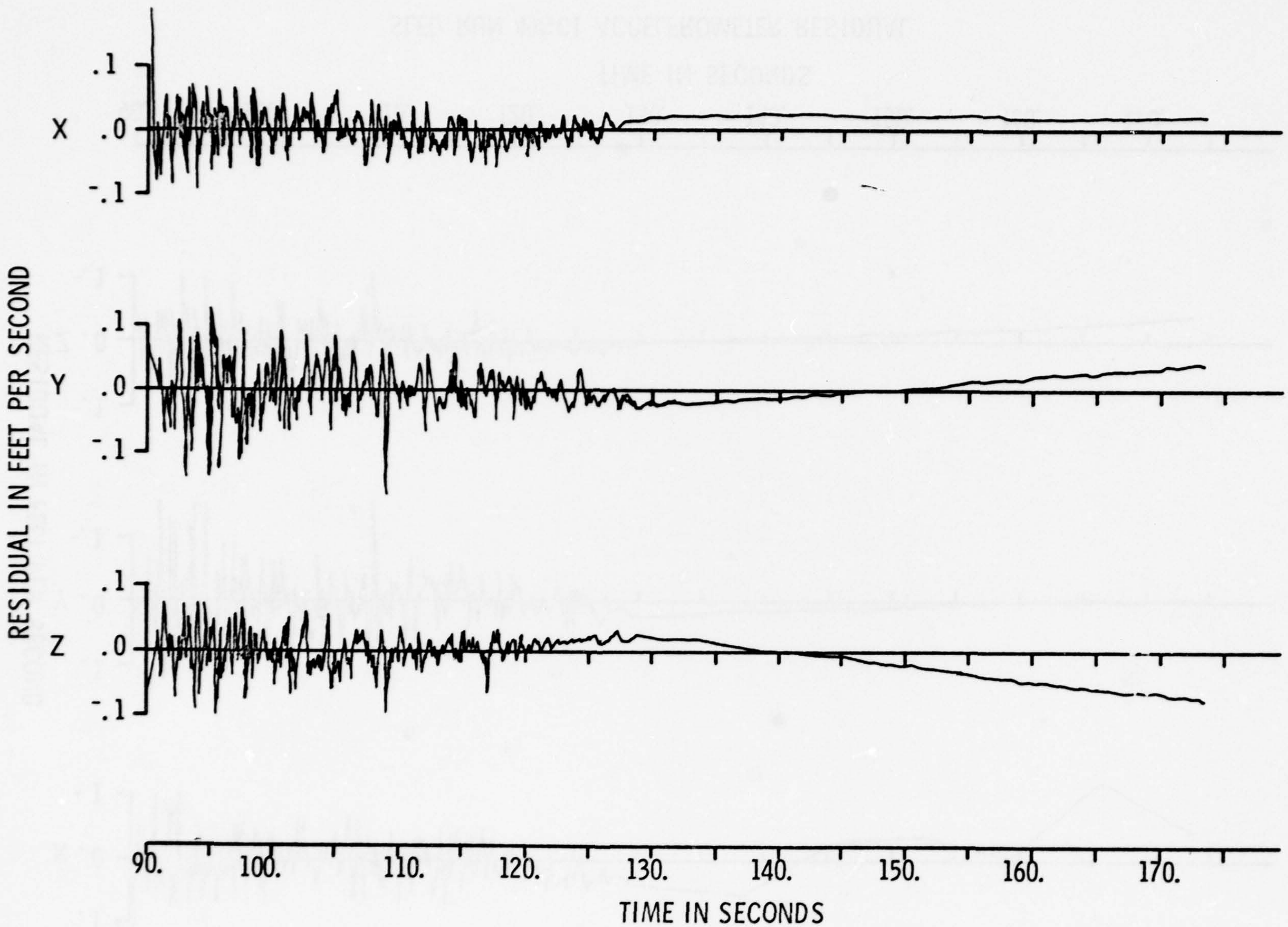
  ASYMMETRIC CROSS-AXIS SENSITIVITIES SLOPES ELIMINATED

- Y, Z ACCELEROMETER ERRORS REDUCED SLOPES ELIMINATED

- Y, Z SYSTEM ERRORS REDUCED SLOPES ELIMINATED




SLED RUN 49GC1 ACCELEROMETER RESIDUAL




SLED RUN 49GC1 ATIGS SYSTEM RESIDUAL

## SLED TEST SUMMARY

- ACCELEROMETERS MAIN ERROR SOURCE
- POSSIBLE GYRO ERRORS
- SYSTEM VELOCITY ERROR MODELED .05 F/S (1 SIGMA)
- STRAPPED-DOWN ALGORITHM ADEQUATE AT 100HZ.
- OPTIMIZE SLED PROFILE

BRIEFING TITLE

# INERTIAL SYSTEMS IN THE INTERNATIONAL ENVIRONMENT - A LOGISTICS PROBLEM

ROBERT VIETROGOSKI
SINGER-KEARFOTT DIVISION
LITTLE FALLS NJ

HARRY NIEWOOD
SINGER-KEARFOTT DIVISION
LITTLE FALLS NJ

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# "INERTIAL EQUIPMENT IN AN INTERNATIONAL ENVIRONMENT – A CHALLENGE IN LOGISTICS SUPPORT"

PRESENTED TO THE

JOINT SERVICES DATA EXCHANGE FOR INERTIAL SYSTEMS

11th ANNUAL CONFERENCE

NEWARK, OHIO

OCTOBER 28, 1977

By

Harry Niewood

Robert Vietrogoski

KEARFOTT DIVISION
THE SINGER COMPANY
LITTLE FALLS, NEW JERSEY

# INERTIAL EQUIPMENT IN AN INTERNATIONAL ENVIRONMENT

## A CHALLENGE IN LOGISTICS SUPPORT

## SINGER-KEARFOTT/INTERNATIONAL PROGRAMS

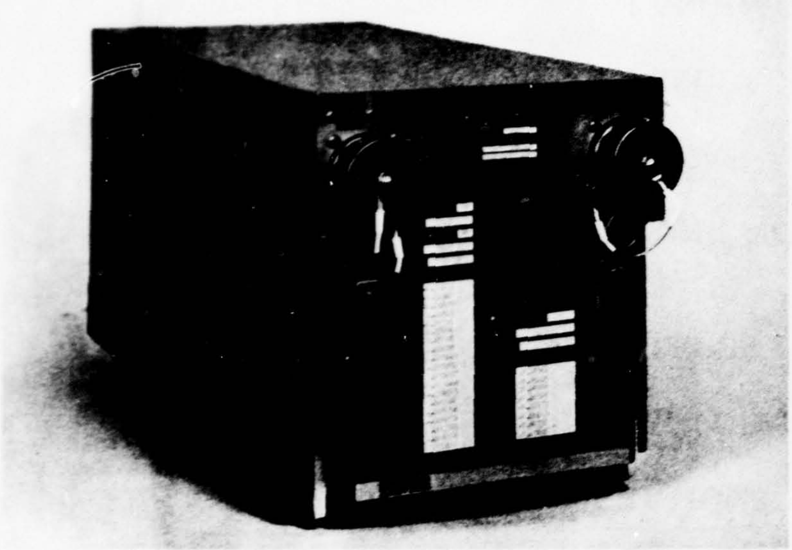
| AIRCRAFT PROGRAM | PROGRAM TYPE | ASSOCIATED ORGANIZATIONS | USING COUNTRY (S) |
| --- | --- | --- | --- |
| F-16 | CO-PRODUCING WITH FOREIGN SUPPLIER | KONGSBERG VAPENFABRIKK, NORWAY | GOVERNMENTS OF BELGIUM, DENMARK, NETHERLANDS, NORWAY |
| JA-37 | PRODUCTION SOURCE TO FOREIGN GOVERNMENT | FORVARETS MATERIELVERK (FMV–F) SWEDEN | SWEDEN |
| F-4 | LICENSE AGREEMENT FOR FOREIGN COUNTRY SUPPORT | TAMAN DIVISION, ISRAEL AIRCRAFT INDUSTRIES | ISRAEL |
| SUPER ETENDARD | LICENSE AGREEMENT FOR FOREIGN COUNTRY PRODUCTION | SAGEM | FRANCE |

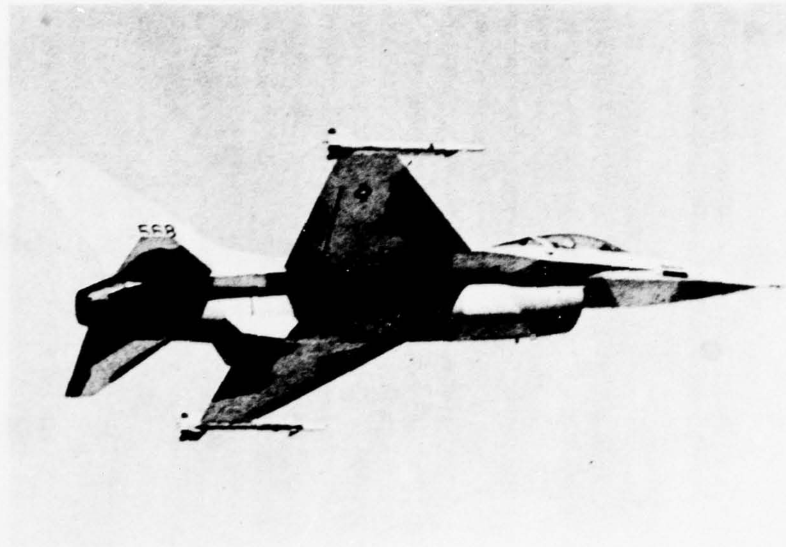
## SINGER-KEARFOTT INTERNATIONAL LOGISTICS

- SUPPORT
  - MAINTENANCE
  - SPARES
  - TRAINING
  - TEST EQUIPMENT/FACILITIES
  - WARRANTY
- OPERATIONS
  - PERFORMANCE
  - STATUS
- COMMUNICATIONS
  - DATA
  - FEEDBACK
  - LANGUAGE

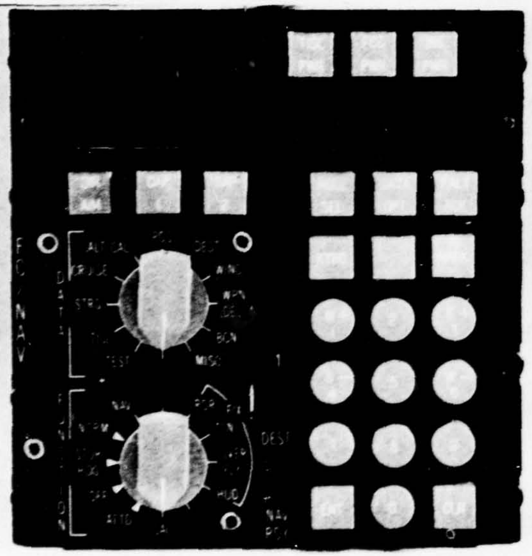
SINGER
KEARFOTT DIVISION

# F-16 PROGRAM





FCNP



**CUSTOMER/USER:**

GENERAL DYNAMICS/USAF/CONSORTIUM

**CONTRACT START:** 4/75

**EQUIPMENT:**

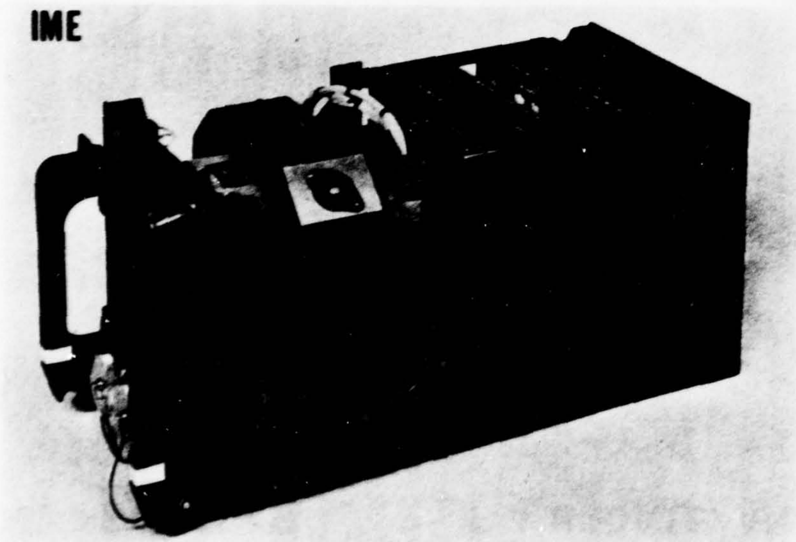
- 8 - FULL SCALE DEVELOPMENT, INERTIAL NAVIGATION SYSTEMS & FIRE CONTROL NAV PANELS
- 998 - PRODUCTION OPTIONS

SINGER
KEARFOTT DIVISION

## JA-37 PROGRAM

COMPUTER

IME



**CUSTOMER USER:**

FMV/SAAB AEROSPACE/SWEDISH A.F.

**CONTRACT START:** COMPUTER 12/71
IME 10/72

**EQUIPMENT:**

- COMPUTER: 16 SKC-2037, LAB/FLIGHT TEST, SOFTWARE, TRANSFER MANUFACTURING TO DATASAAB
- IME: 9 DDT & E, 165 PRODUCTION, FLIGHT TEST PROGRAM

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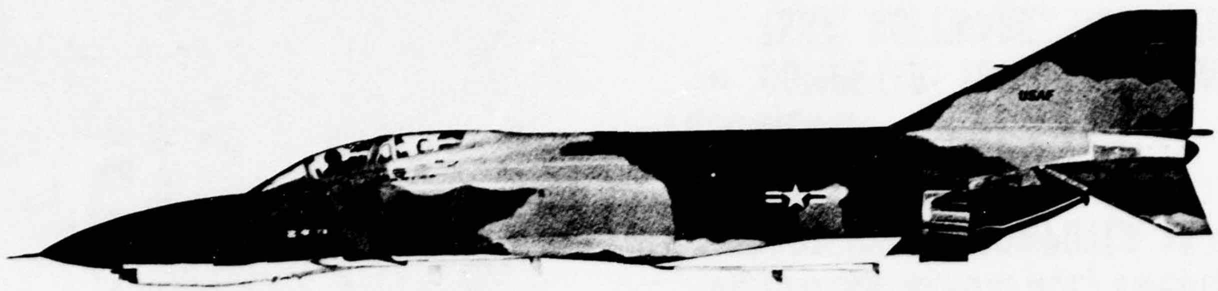
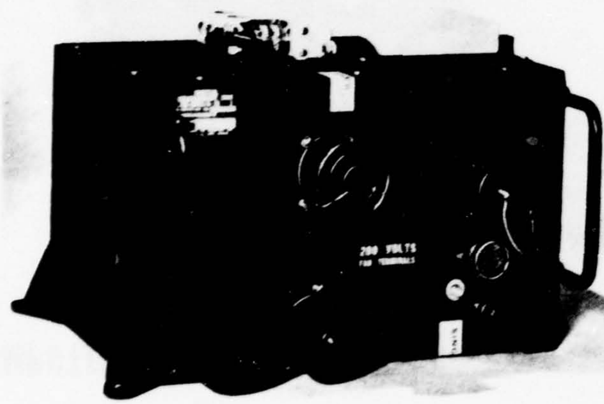
KEARFOTT DIVISION

# F-4 UPDATE, AN/ARN-101 PROGRAM




CUSTOMER/USER: USAF, ASD, AFSC

CONTRACT START: 6/76

FLIGHT TEST: EXTENSIVE EVALUATION AT EGLIN AFB

EQUIPMENT:

- 5 PROTOTYPE INERTIAL MEASUREMENT UNITS
- 288 PRODUCTION FOLLOW-ON

FOREIGN F-4E UPDATE APPLICATIONS

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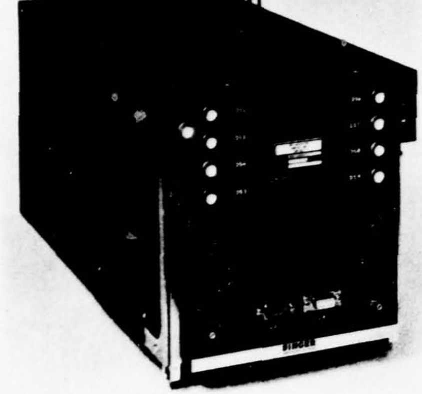
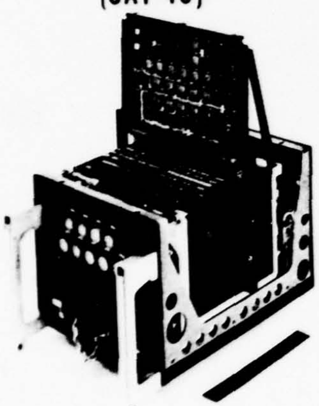
KEARFOTT DIVISION

# SUPER ETENDARD PROGRAM

INERTIAL NAVIGATION UNIT



WEAPON DELIVERY UNIT
(UAT-40)



**CUSTOMER/USER: SAGEM/FRENCH NAVY**

**CONTRACT START: 10/73**

**EQUIPMENT:**
**SKN-2600 SERIES NAVIGATION/WEAPON DELIVERY SYSTEMS**

## SHARED ACTIVITIES

| PROGRAM | CO-PRODUCING SOURCE | ACTIVITY |
|---|---|---|
| F-16 | KONGSBERG, KV | INU |
| | | FCNP |
| | | BATTERY |
| | | INU MOUNT |
| JA-37 | NO PRODUCTION ACTIVITY | DEPOT REPAIR |
| F-4E | TAMAM | DEPOT REPAIR |
| | | IMU |
| SUPER ETENDARD | SAGEM | INU |

## MAINTENANCE CONCEPT

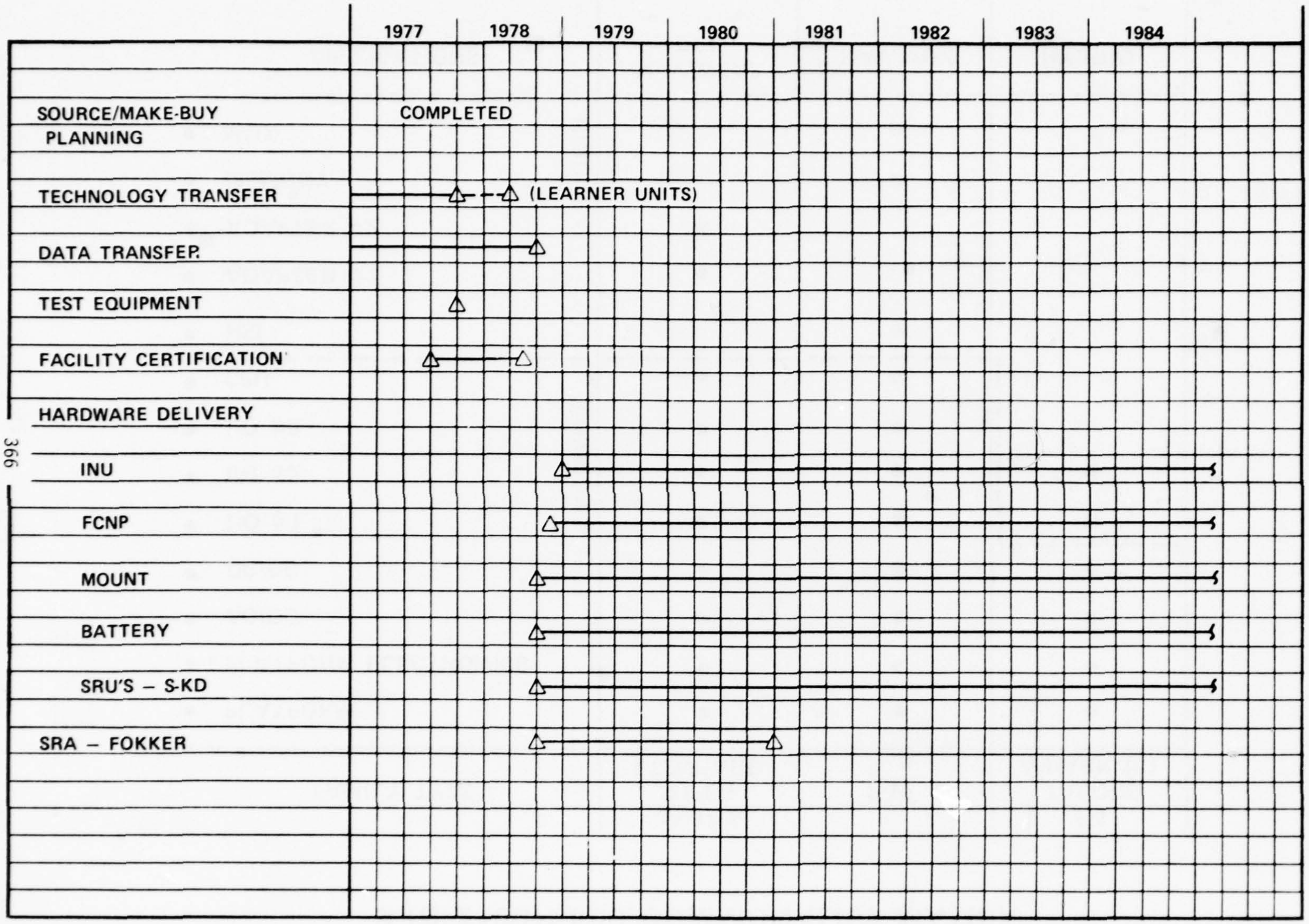
| PROGRAM | MAINTENANCE ACTION: ORGANIZATION | MAINTENANCE ACTION: INTERMEDIATE | MAINTENANCE ACTION: DEPOT |
|---|---|---|---|
| F-16 | REMOVE & REPLACE LRU'S<br>ACTION: USER'S-EPG | 1-18 MONTHS-LRU VERIFICATION<br>19-48 MONTHS-SRU REMOVE/REPL.<br>ACTION: USER'S-EPG./GD | TOTAL REPAIR<br>ACTION: S-KD DEPOT |
| JA-37 | REMOVE & REPLACE LRU<br>ACTION: SWEDISH AF | (NOT APPLICABLE) | TOTAL REPAIR<br>(NOT INCLUDING SENSORS)<br>ACTION: CVM DEPOT |
| F-4E | REMOVE & REPLACE LRU<br>ACTION: ISRAEL AF | LRU VERIFICATION & SRU<br>REMOVAL & REPLACEMENT<br>ACTION: ISRAEL AF<br>CONTRACTOR ASSIST | TOTAL REPAIR<br>ACTION: S-KD/TAMAM DEPOT |
| SUPER ETENDARD | REMOVE & REPLACE LRU<br>ACTION: FRENCH NAVY | LRU VERIFICATION & SRU<br>REMOVAL & REPLACEMENT<br>ACTION: FRENCH NAVY<br>CONTRACTOR ASSIST | TOTAL REPAIR<br>ACTION: SAGEM DEPOT<br>(NOT INCLUDING SENSORS) |

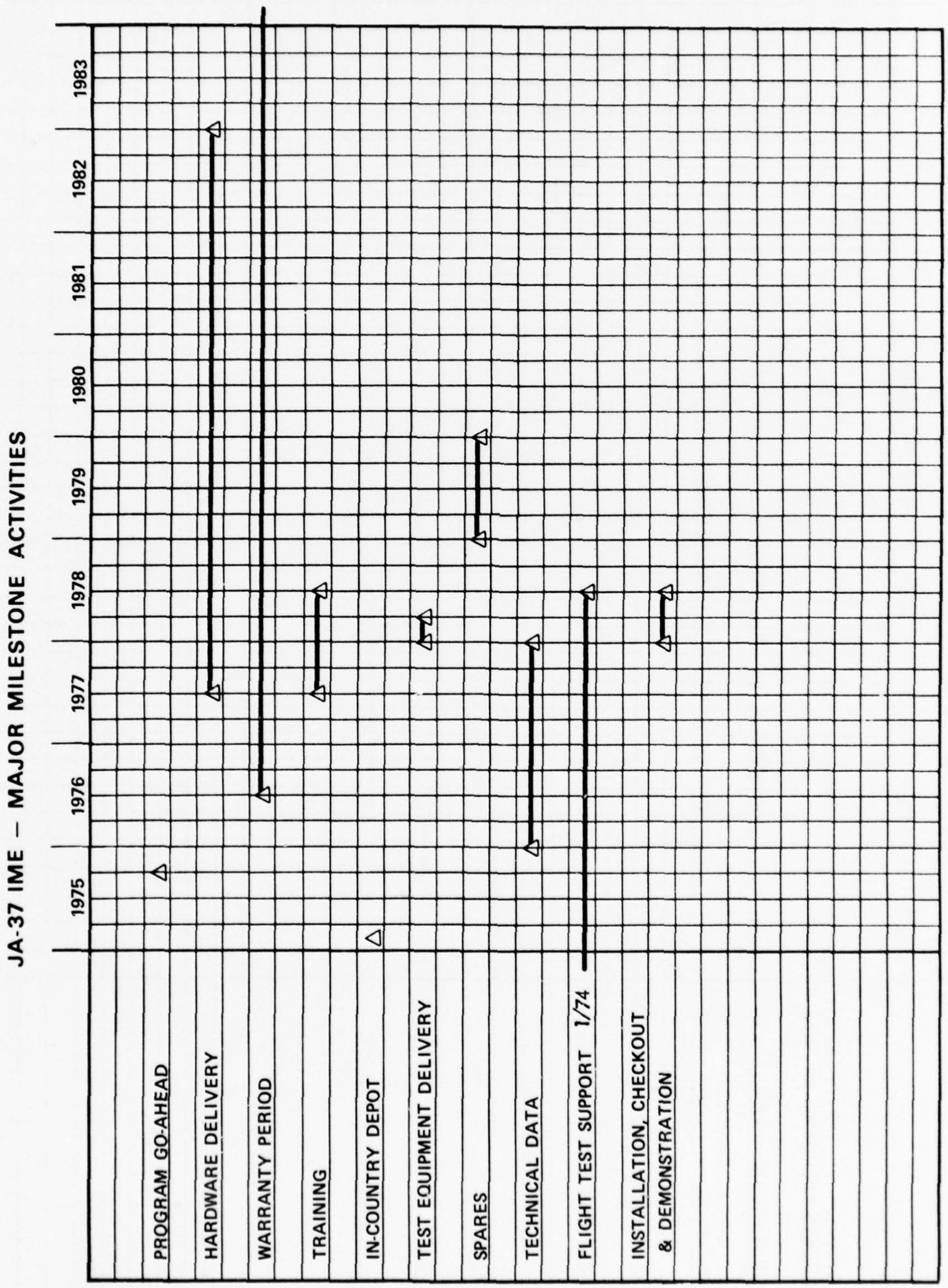

SINGER
KEARFOTT DIVISION
F-16 INU
CPU
I/O NO. 2
I/O NO. 1
DC/DC
PLAT ELEX
SERVO
I/O NO. 3
MUX NO. 1
MUX NO. 2
PROM
HSI
AC/DC

# SKN-2400/2600 COMMONALITY MATRIX

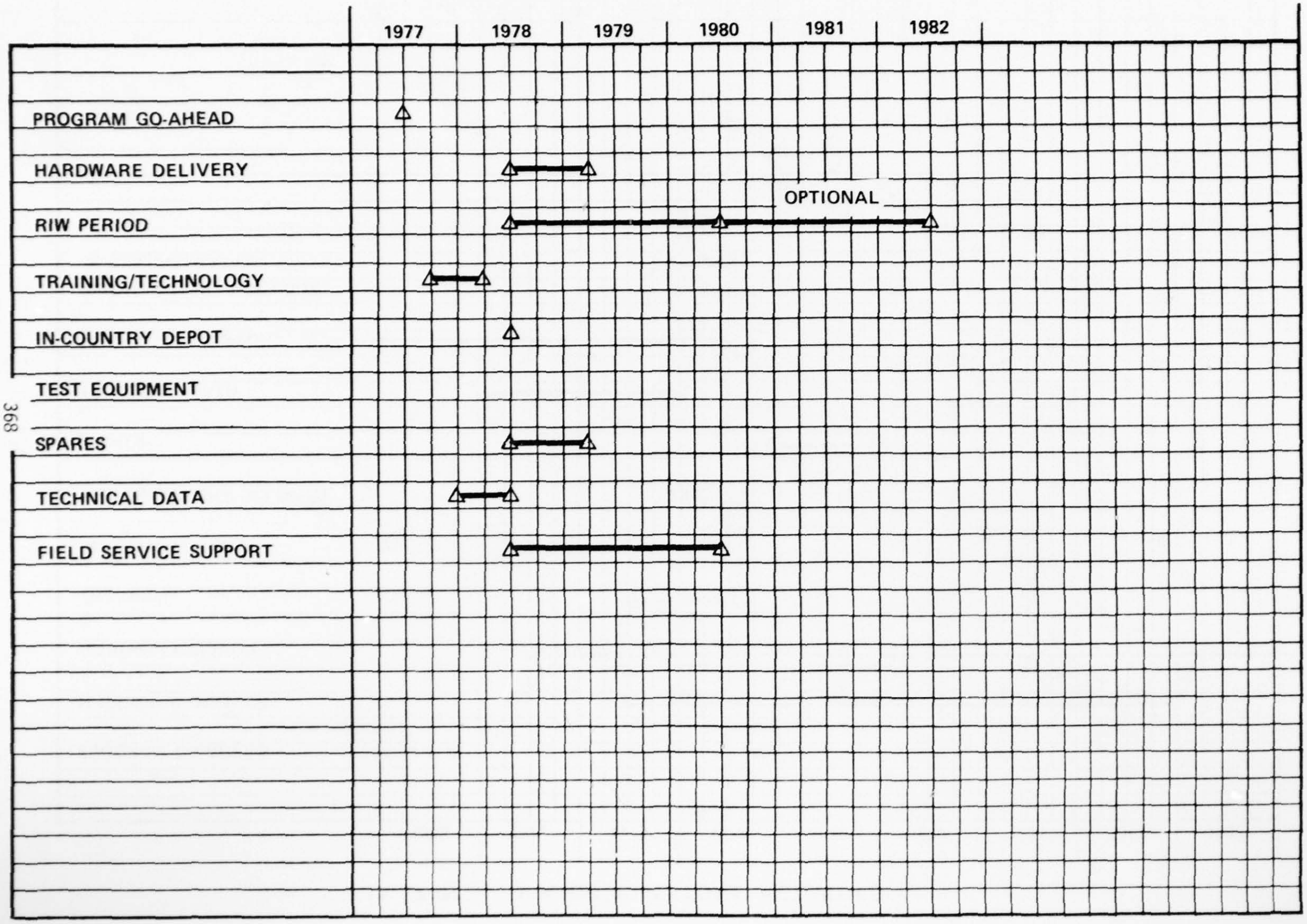
| | FAMILY TYPE | JA-37 & SUPER ETENDARD | F-16 | F-4 TALONS AN/ARN-101 |
|---|---|---|---|---|
| COMMON | • PLATFORM | ● | ● | ● |
| | • PLATFORM ELECTRONICS | ● | ● | ● |
| | • AC/DC | ● | ● | ● |
| | • DC/DC | ● | ● | ● |
| | • I/O #1 | ● | ● | ● |
| | • I/O #2 | ● | ● | ● |
| | • I/O #3 | ● | ● | |
| | • CPU | ● | ● | |
| UNIQUE | • HSI | | ● | |
| | • ADAPTER #1 | ● | | |
| | • ADAPTER #2 | ● | | |
| | • MEMORY | | ● | |
| | • MUX | | ● | |
| | APPLICATIONS | NAV/WEAP DEL | NAV/MUX | HYBRID |

## F-16 MAJOR MILESTONE ACTIVITIES -KV

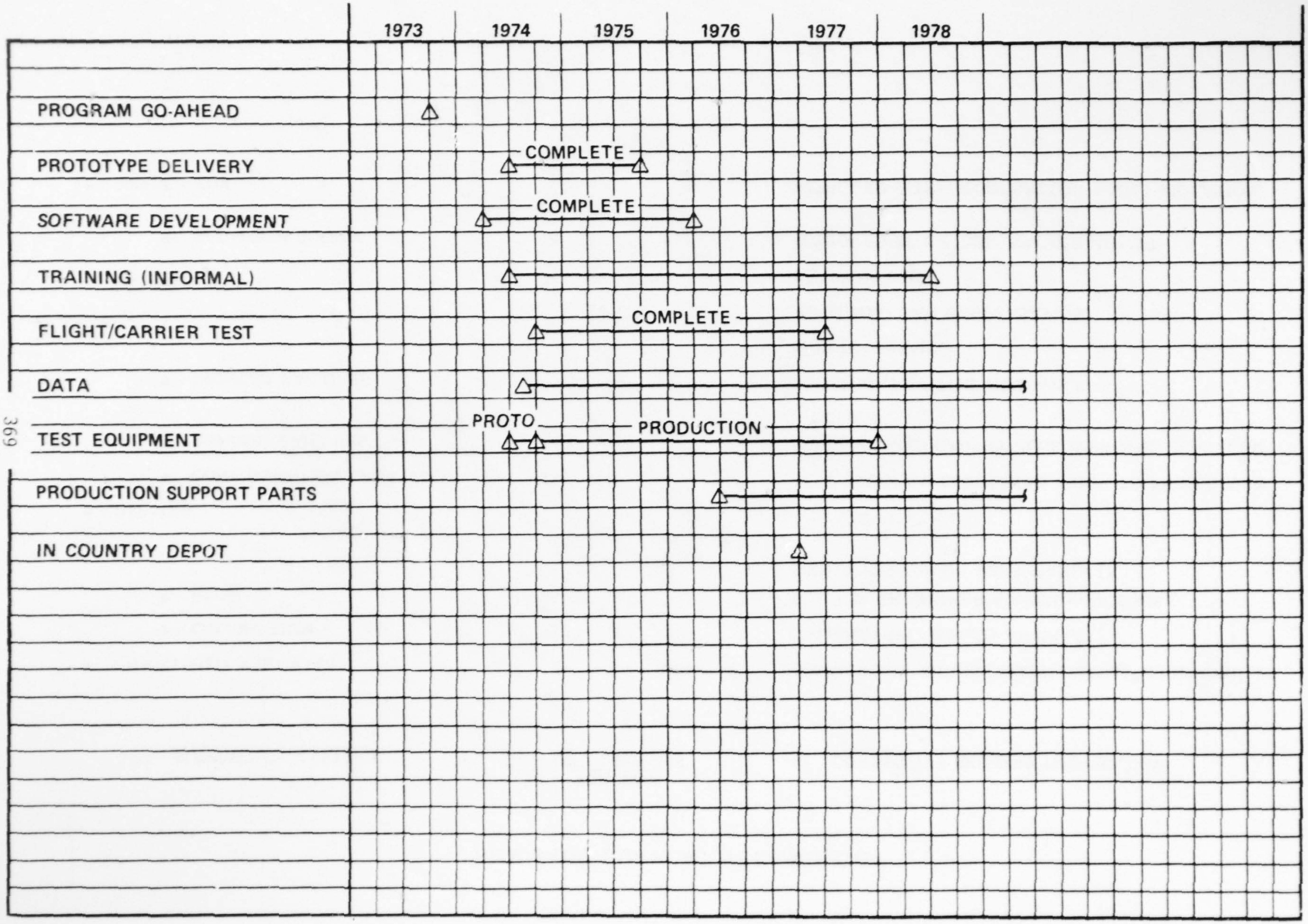



JA-37 IME — MAJOR MILESTONE ACTIVITIES
1975
1976
1977
1978
1979
1980
1981
1982
1983
PROGRAM GO-AHEAD
HARDWARE DELIVERY
WARRANTY PERIOD
TRAINING
IN-COUNTRY DEPOT
TEST EQUIPMENT DELIVERY
SPARES
TECHNICAL DATA
FLIGHT TEST SUPPORT 1/74
INSTALLATION, CHECKOUT
& DEMONSTRATION

## F-4 IMU – MAJOR MILESTONE ACTIVITIES



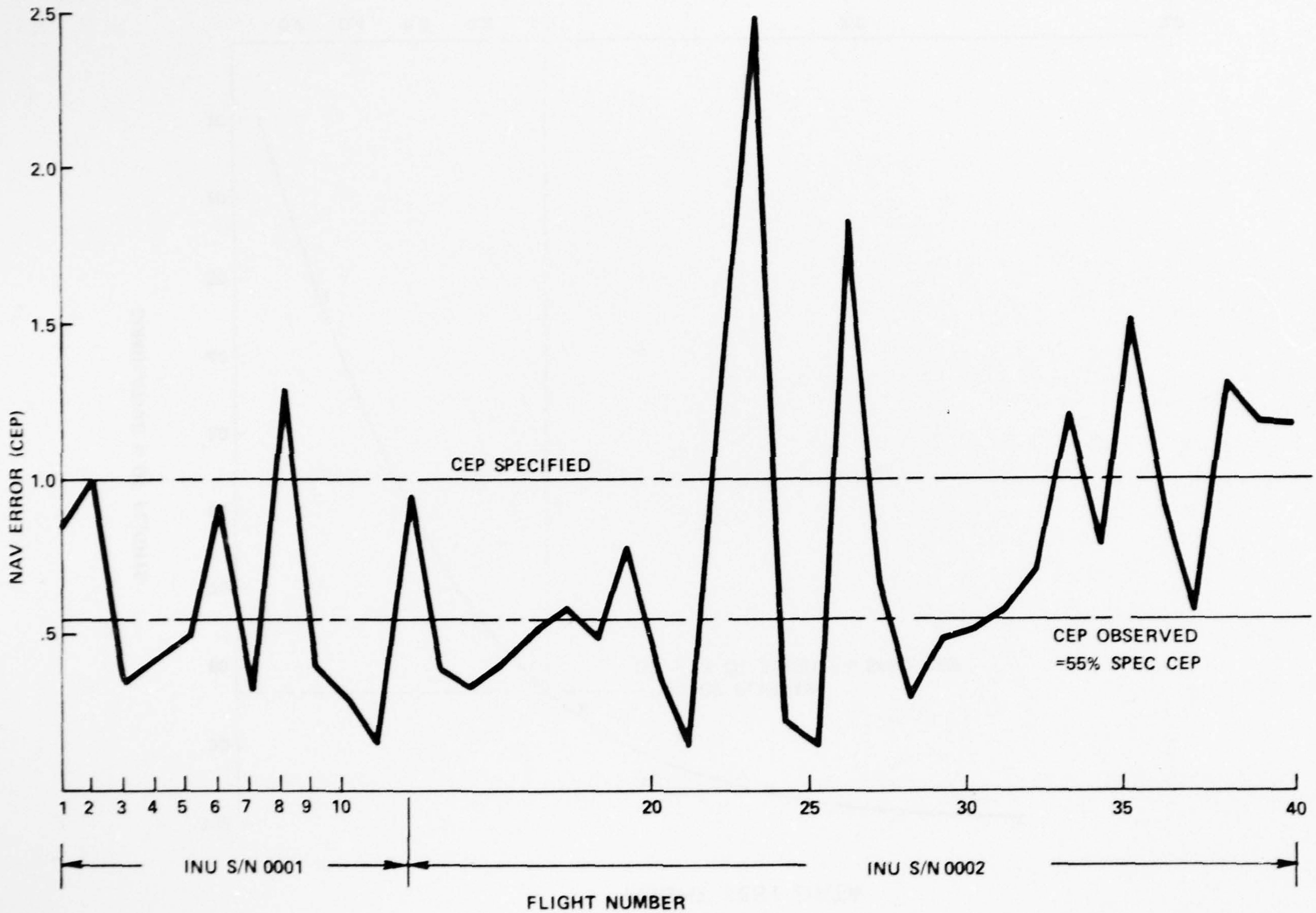
## SUPER ETENDARD MAJOR MILESTONE ACTIVITIES



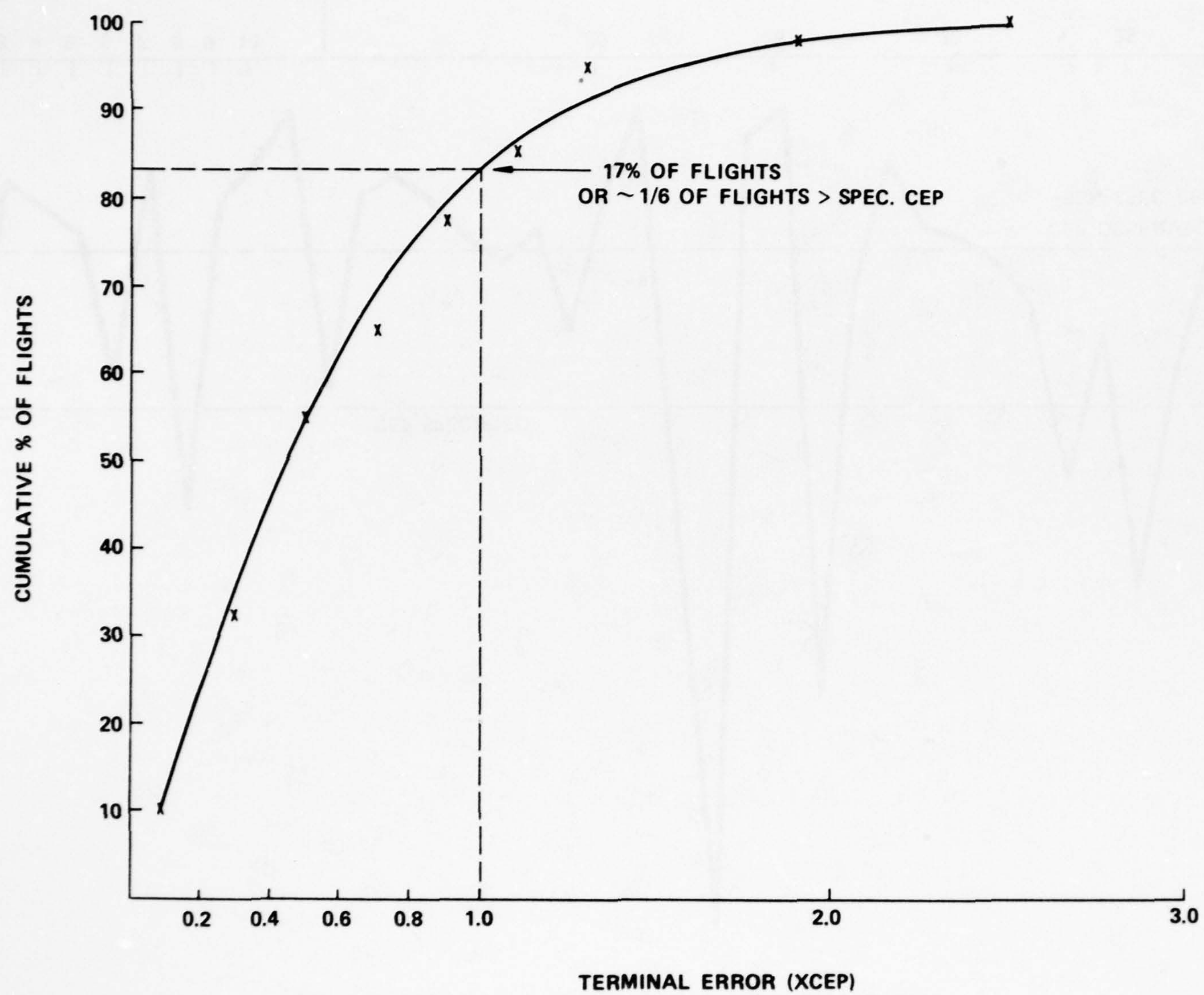
# SKN-2400 SUPPORT TECHNOLOGY

| SUPPORT CHALLENGES | PERCENT OF REMOVALS | | CORRECTIVE SKN-2400 TECHNOLOGY |
|---|---|---|---|
| • UNJUSTIFIED REMOVALS | | 61 | COMMERCIAL AIRLINE MAINTENANCE GROUNDRULES. |
| • CALIBRATION | 35 | | CALIBRATION ABOARD AIRCRAFT. |
| • RTOK | 26 | | BUILT-IN TRAINING & MAINTENANCE AIDS.<br>S-KD APPROVAL OF USER MANUALS. |
| • REPAIRS | | 36 | |
| • CONFIGURATION UPDATES | 13 | | TEST PROGRAM COMPLETED PRIOR TO PRODUCTION |
| • RANDOM FAILURES | 12 | | MORE MICROCIRCUITRY PLUS IMPROVED PLATFORM DESIGN. |
| • INDUCED FAILURES | 7 | | FEWER UNJUSTIFIED REMOVALS.<br>MUX INTERFACE.<br>AUTO MAG VAR COMPENSATION.<br>BATTERY VECP. |
| • BAD FROM SUPPLY | 4 | | IMPROVED BITE + CONTRACTOR REPAIR. |
| • DEPOT RTOK | | 3 | IMPROVED BITE + CONTRACTOR FAULT ISOLATION. |
| | | 100 | |

## RECENT USAF SKN-2400 INS FLIGHT TESTS TERMINAL NAVIGATION ERROR/FLIGHT DATA



## RECENT USAF SKN-2400 INS FLIGHT TEST DATA



## MTBMA vs CEP FOR S-KD INERTIAL SYSTEMS

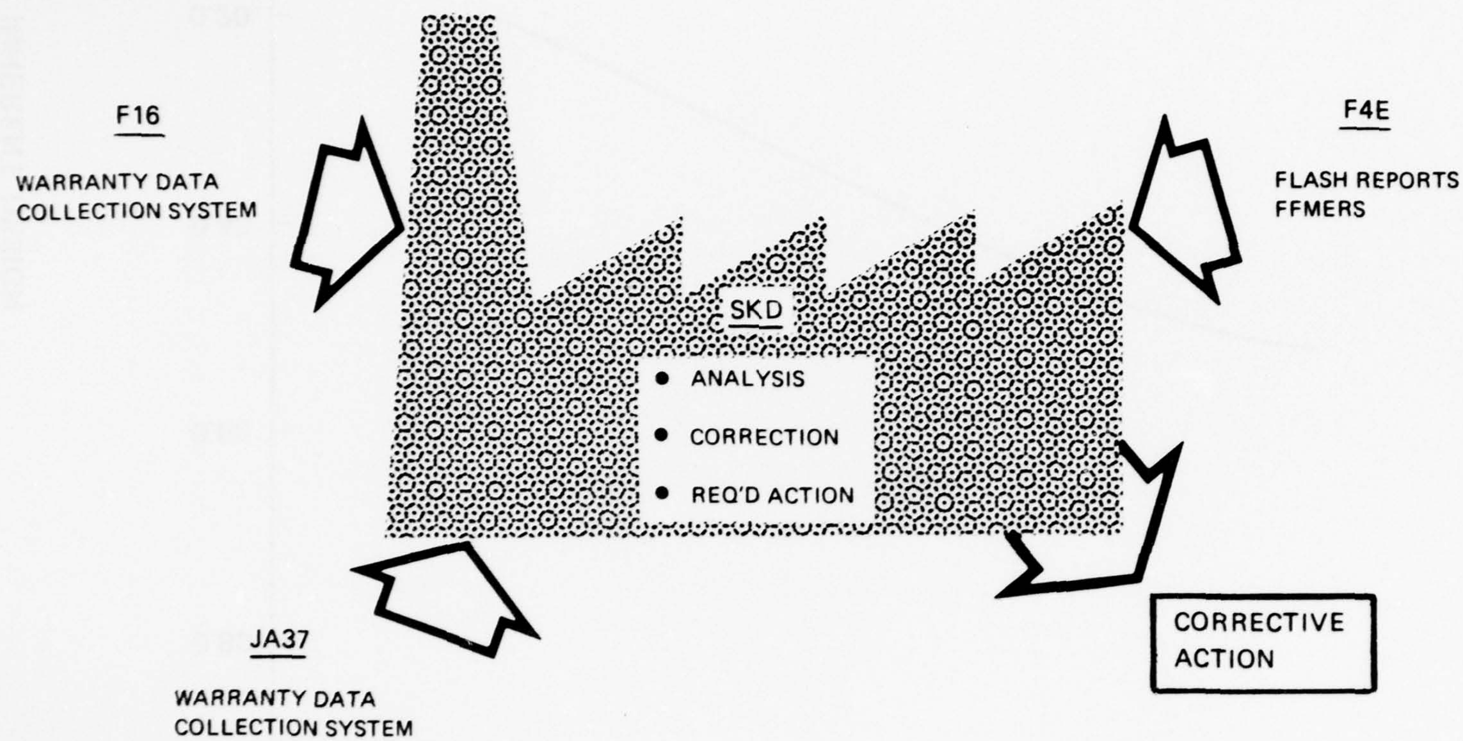
| A/C | INERTIAL SYSTEM | A/C NAV. SPEC. CEP (nmi/h) | OBSERVED PERCENT OF FLIGHTS > SPEC. | AVG. FLIGHT TIME/FLIGHT (hours) | ESTIMATED FLIGHT TIME PER PILOT SQUAWK | MILITARY REPORTED MTEMA |
|---|---|---|---|---|---|---|
| P-3C | ASN-84 | 1.0 | 45% | 5.5 | 12.2 | 12.3* |
| A-7D/E | ASN-90 | 2.0 | 17% | 1.9 | 11.2 | 13.0* |

*REPORTED BY 3M FOR PERIOD 10/74 - 9/75

## PENDING ACTION FOR INERTIAL SYSTEM REMOVAL PROBLEMS

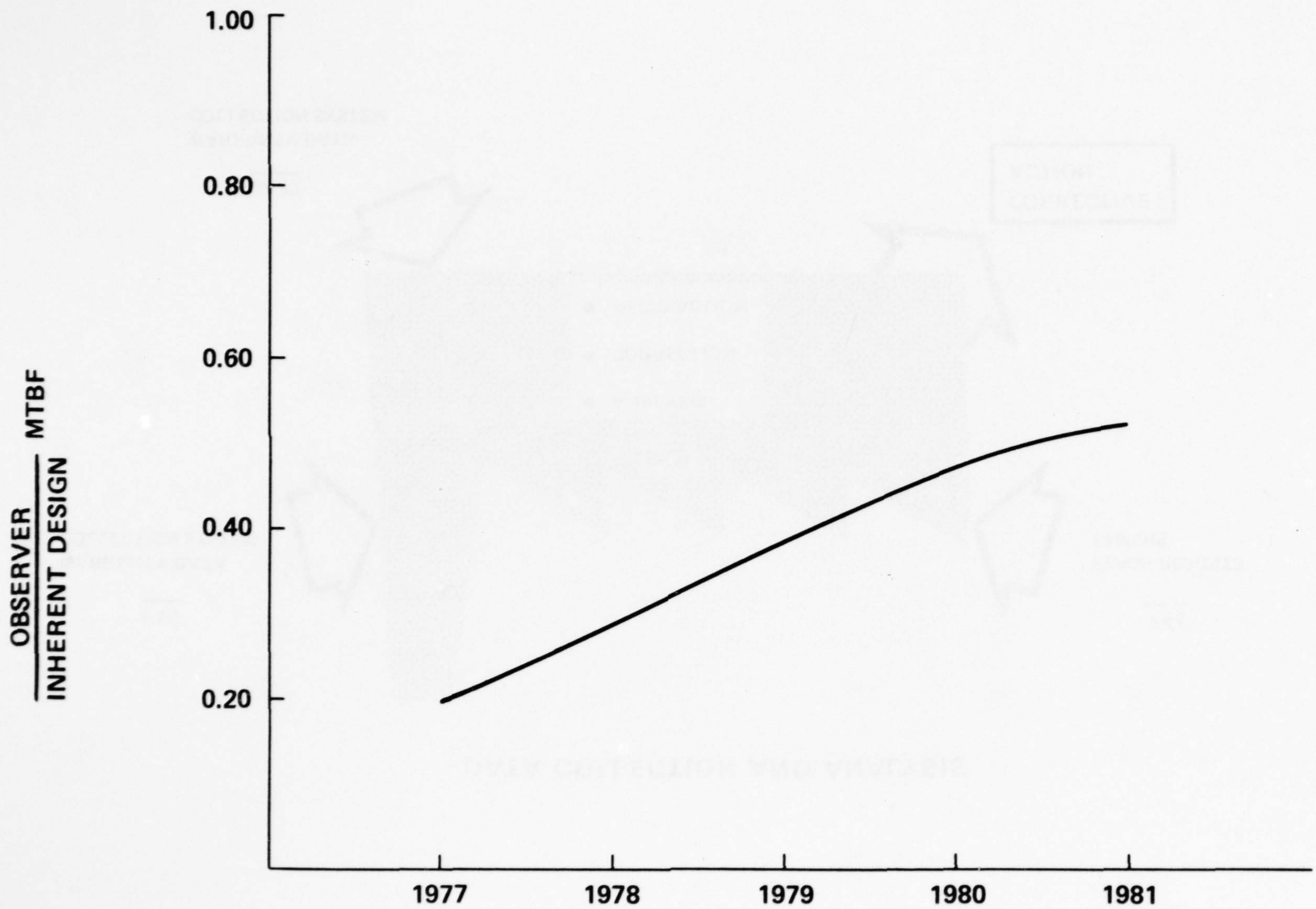
- THE PRIME CONTRACTOR (S) AND THE USERS TO INCORPORATE AND ENFORCE COMMERCIAL AIRLINE RULES FOR INITIATING MAINTENANCE ACTION ON INERTIAL NAVIGATION EQUIPMENT

## DATA COLLECTION AND ANALYSIS



## FIELD OPERATIONS RELIABILITY GROWTH

FOR FIGHTER AIRCRAFT



## INERTIAL SYSTEMS IN THE INTERNATIONAL ENVIRONMENT - A LOGISTICS PROBLEM

| PROBLEMS | SOLUTIONS | RESULTS |
| --- | --- | --- |
| • EXISTING | | |
| – UNJUSTIFIED REMOVALS | COMMERCIAL AIRLINES MAINTENANCE RULES. | REDUCED SUPPORT COSTS |
| – RANDOM FAILURES | OPERATIONAL HARDWARE/ SOFTWARE IMPROVEMENTS. | + |
| – CONFIGURATION UPDATES | ALL TESTS COMPLETED PRIOR TO LARGE SCALE PRODUCTION. | INCREASED READINESS |
| • NEED FOR DATA FEEDBACK | CONTRACTOR REPAIR AND DATA SYSTEMS. | |

# LESSONS LEARNED
# WORKSHOPS

WE HAVE REPRODUCED VERBATIM THE TAPES TAKEN DURING THESE WORKSHOPS - WHERE THE QUALITY OF THE TAPE OR THE REMARKS OF AN ATTENDEE WERE NOT CLEAR OUR TRANSCRIBER DID THE BEST SHE COULD.

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MAINTENANCE LESSONS LEARNED WORKSHOP

CHAIRMEN

JOE KENNEDY
AEROSPACE GUIDANCE & METROLOGY
CENTER
NEWARK AFS OH

JOHN McHALE
HQ NAVAL AIR SYSTEMS COMMAND
WASHINGTON D.C.

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SESSION II

MAINTENANCE LESSONS LEARNED WORKSHOP

WEDNESDAY, 26 OCTOBER 1977

CO-CHAIRMEN: JOE KENNEDY
DIRECTORATE OF INERTIAL ENGINEERING, AGMC

JOHN McHALE
HQ NAVAL AIR SYSTEMS COMMAND

BURKE HALL - DENISON UNIVERSITY

TOPIC: INERTIAL NAVIGATION SYSTEMS WEAPONS REPLACEABLE ASSEMBLIES (WRA) TESTING PHILOSOPHY

DISCUSSION: INERTIAL NAVIGATION TESTING PHILOSOPHY SHOULD AGREE WITH THE SYSTEM DESIGN (TEST POINTS AVAILABILITY, ETC.) AND SHOULD REFLECT THE AIRCRAFT CIRCUITRY WHEN POSSIBLE AS WELL AS SOFTWARE TESTING AGREE WITH THAT OF OPERATIONAL ASPECTS.

LESSONS LEARNED:
(1) OPERATOR TRAINING
(2) SUFFICIENT NUMBER OF TEST POINTS
(3) PROPER CIRCUIT LOADING
(4) ALL CIRCUITS ENERGIZED
(5) THIRD AND FOURTH PARTIES
(6) CONE OF TOLERANCE

GREENING-NAVY: Good afternoon. I don't see anybody falling asleep yet, so I hope I don't put you over the brink.

What I'm going to do is read the items. My name is Jim Greening from Naval Aviation Engineering Service Unit at Ociana, Virginia Beach. And I'm reading this for Roger Logan. He was originally supposed to make the presentation and because of other commitments was not able to make it. So I'm going to read through the topics and the lessons learned and then we'll go back and discuss the items one at a time.

All right. Inertial navigation systems weapon replaceable assembly (WRA), (LRU) for the Air Force, testing philosophy.

Discussion: Inertial navigation testing

philosophy should agree with the system design (test points availability, etc.) and should reflect aircraft circuitry when possible as well as software testing agree with that of operational aspects.

Under lessons learned, (1) Operator training. Operators may not have as much training for processing WRA's. However many of the automatic test stations are so sophisticated that an extreme amount of training must be given to support them.

The second one is sufficient number of test points. The systems under test must be designed for automatic testing. A sufficient number of breakout points must be available to monitor each stage of a circuit to determine if it is operating properly and most of all to fault-isolate.

Number three, proper circuit loading. Circuitry loading must be in the same manner as that of the system in order to have proper circuitry reaction to the load and to prevent compatability problems between aircraft operation and automatic testing.

Number four, all circuits energized. In systems that have many circuits working together, all circuitries should be interfaced such that they are energized together rather than one circuit at a time to insure proper circuitry compatability within a unit.

AD-A061 615 AEROSPACE GUIDANCE AND METROLOGY CENTER NEWARK AIR FO--ETC F/G 17/7
CONFERENCE PROCEEDINGS OF THE DATA EXCHANGE FOR INERTIAL SYSTEM--ETC(U)
OCT 77 E T BODEM

UNCLASSIFIED AGMC/XR-77-1 NL

5 OF 8

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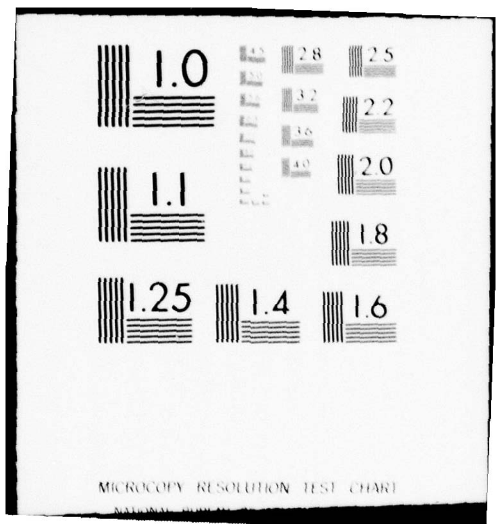
1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
MICROCOPY RESOLUTION TEST CHART

Number five, third and fourth parties. Many of our problems here stemmed from third and fourth parties building the test equipment or writing the test programs. Many times not enough data is available to these third and fourth parties to adequately design test equipment or to write test programs for system support. Test programs while written for component parameter evaluation must stimulate these components in the same manner as the system software.

Number six, cone of tolerance. Cone of tolerance must be used with smaller tolerance at each higher level of maintenance to insure proper operational relationship with interfacing system at aircraft level.

As far as the Navy is concerned, and the LN-2 program, which is what I'm referring this to is because this is where we originated so many of our problems.

Under number one, operational training, this is a system whereby we used the ANTC test bench, which was an easy-to-use pushbutton type automatic testing assembly. And in some cases now, of course, the Navy has gone to VAST, whereby the operator only has to know the sequence and what readouts are available to him and what readouts are necessary for him to use and then there's no real responsibility on his part as far as the test equipment itself is concerned.

This is the part where it's becoming so sophisti-

cated that should a malfunction occur that he doesn't recognize or can't associate with what he's been trained, then as far as he's concerned, it's all over. I'm sure many of the others, you know, various types of programs have run into the same situation.

Under sufficient number of test points, this was a case whereby we were using an analog system and using digital test equipment so that there was no or a minor degree of compatability of such that when the systems were put into the aircraft, they very rarely worked and our failure -- I guess our percentage of failure was running 60 to 70 percent on just about any of the boxes in the systems and the platform that you could name. It got to be so bad that we had to go to a hot bench concept whereby we duplicated the aircraft system and just ran it using chart recorders because we were not able to get the degree of output from the automatic test equipment that we wanted.

Number three, circuitry loading. Here again, we ran into a problem whereby it was an analog system and we were adapting it to digital systems and the circuitry loading from the test equipment portion of it was so completely foreign to what we wanted as far as the relation to actual aircraft systems,that it presented quite a problem.

Number four, all circuits energized. Here was

a case of using automatic test equipment to energize circuits in a certain sequence and in at certain times and not leaving these curcuits energized for later portions of the test where the same circuit would be used again. However, since it had been de-energized because it had only been looked at once, and of course it wasn't energized during the course in the period when we needed it again, there was no interfacing between sections of the circuits so that we could tie the two together and make sure we didn't have a problem in relating the two.

Number five, third and fourth parties. This was a case where one company designed the system and another company made the test equipment and designed the test programs without having the system that it was using physically at hand and it generated a lot of problems and it took a lot of time to get over that point and as a matter of fact until recently we weren't sure we were even over it and the system has been out and in use for 15 years, or 20 years, something in that order.

Cone of tolerance. Here's another situation whereby the system was designed to a certain tolerance. In being tested, the tolerance seemed to widen to the point that by the time it got to the aircraft, the tolerances had widened past the point where the system

required -- the overall integrated system, so that we had to go back and redo the testing procedures starting at the system outlet working back and make sure that we were compatible on each step from the depot level all the way to the actual line -- the intermediate level.

That's all I have. Does anybody care to discuss any of the points?

LOGUS-ASD: I don't think that on Item 5 we've really progressed very far. We're still involved with companies who build the inertial and separate companies who provide us with the test equipment and that's a true case I think in all our recent weapon systems, and no change in sight.

GREENING-NAVY: The commercial people do it otherwise.

LOGUS-ASD: I'm talking about us in the Air Force.

GREENING-NAVY: We could learn from commercial people in that area.

LOGUS-ASD: We're all aware of it. I don't know -- you know, the question of what you mean by the definition of learning.

GREENING-NAVY: I think you can probably get most of the people in the maintenance end of it to agree, you know, to agree to your point because we don't make the decision as to who writes the test procedure and who makes

the test equipment, so I don't think you'll get much argument on that point.

THOMAS-SASO: When you speak of cone of tolerance, what percentage are you changing it out in the field over the aircraft as versus back where you repair it?

GREENING-NAVY: Percentage-wise, I really can't say specifically, because I didn't bring it with me, but it got to the point that the testing or the tolerances that were being used at the depot level were wider than the tolerances that we required on the aircraft itself as far as completing the mission was concerned. In other words, drift-related characteristics, things on that order.

THOMAS-SASO: Didn't you make them tighter at the depot so that when you took them out in the field there wouldn't be an argument, say one was right close on the line or you said there was an argument on which side of the line it was on?

GREENING-NAVY: Well, I wasn't working at the depot level and there was a misunderstanding from the intermediate level as to what the tolerances were supposed to be and that was where the problem came in. Working at an intermediate level our tolerances were actually tighter than what the depot at the present time was using, you know. The situation has since been alleviated, but it's more of a lack of communication than anything else.

McHALE-NAVY: Okay. Next we'll have -- thank you, Jim. Captain Denny Robinson from AGMC.

- - -

TOPIC: CONSIDERATIONS FOR ATE SELECTION

DISCUSSION: THE USE OF AUTOMATIC TEST EQUIPMENT (ATE) IN THE REPAIR OF INERTIAL SYSTEMS IS INCREASING YEAR AFTER YEAR. WITH THE SPIRALING COST OF ATE AND ITS SUPPORT, CAREFUL CONSIDERATION SHOULD BE GIVEN TO ALTERNATE METHODS TO FUNCTIONALLY TEST AND FAULT ISOLATE A PARTICULAR UNIT UNDER TEST (UUT). THIS PRESENTATION WILL INCLUDE:

(1) TRADITIONAL ADVANTAGES OF ATE
(2) REAL COST OF ATE
(3) ALTERNATIVES TO TOTAL AUTOMATION
(4) CONSIDERATIONS FOR APPROACH SELECTION

LESSONS LEARNED: AN EXTENSIVE STUDY SHOULD BE MADE BEFORE SELECTING YOUR APPROACH OF TESTING AND FAULT ISOLATION. ALTHOUGH MANY CONSIDERATIONS SHOULD BE INCLUDED IN THIS STUDY, THE ULTIMATE GOAL IS COST EFFECTIVENESS AND NOT "TRADITIONAL ADVANTAGES."

TRADITIONAL ADVANTAGES OF ATE
- SPEED
- RELIABILITY
- REPEATABILITY
- REDUCTION OF OPERATOR GRADE

REAL COST OF ATE (INCREASES WITH COMPLEXITY)

- INITIAL COST
- SUPPORT SOFTWARE
- SUPPORT HARDWARE AGE FOR AGE FOR AGE . . .
- TRAINING
  - OPERATION
  - MAINTENANCE
  - PROGRAMMING (LEARNING NEW TEST LANGUAGE)

- CONTROL AND MAINTAINING ATE CONFIGURATION
  - SOFTWARE AND HARDWARE

- ETC.

ALTERNATIVES TO TOTAL AUTOMATION

THROW AWAY
MANUAL
KNOWN GOOD MODULE APPROACH
SEMI-AUTOMATIC
SEPARATION OF FUNCTIONAL TEST FROM FAULT ISOLATION

CONSIDERATIONS FOR APPROACH SELECTION

1 TECHNICAL ABILITY AND EXPERIENCE OF THE TECHNICIAN
2 NUMBER OF UNITS (WORKLOAD)
3 COMPLEXITY OF UUT
4 COST OF UUT
5 "REAL" COST OF AUTOMATION
6 PARTICULAR APPLICATION

ROBINSON-AGMC: Good afternoon. Captain Robinson from AGMC again, I would prefer not to read this if every-one can see it.

I'm not going to be presenting anything new, per se. From a lot of ATE products which we have seen, most of us, I think there's ample justification however for lessons learned. Most of our problems with ATE I feel can be solved right at the very beginning of the program with the selection and procurement of the ATE.

I plan on giving you a brief background and then go right into the lessons learned which is considerations for ATE selection.

Most everyone -- there seems to be a tendency to have the biggest, the fastest, the most modern state-of-the-art equipment. I'm not sure where this comes from -- I think it's just human nature. I'd like to propose

that the only valid reason for automation is the making or saving of money and not necessarily traditional advantages. Any criteria you are using besides saving money or for cost avoidance, you are really being misled. Traditional advantages may or may not be valid in your application. They may break down. Especially in a depot-type environment.

Most of you are familiar with costs of ATE as well as I am so I'm not going to cover these in detail. This is really put up here as a reminder and with one additional point that these relative costs go up with the complexity of the equipment and with the degree of automation.

There are literally hundreds of testing and fault isolation concepts and I certainly don't have the time to go into really any of them now. I did want to present a few just to establish a background and a frame of reference for which our lesson leanred will be more meaningful.

The first two are pretty much self-explanatory. The known good module approach is simply the comparison of a faulty unit under test (UUT) to a good unit under test. A semi-automatic approach is an approach where you can automate the functions that are done many, many times and leave manual the functions which are either done

very few times or are very complex or are very costly to do automatically.

In a separation of functional test from fault isolation it may be in your best interest to -- if a piece of automatic test equipment decides if a unit is bad or good to take that to a remote station to let someone, a technician, mainly probe the device to fault isolate it rather than tying up the very expensive piece of automatic test equipment. This allows the automatic tester to do what it can do best.

Now for our lessons learned. Basically, it's don't always automatically take the newest, the fastest, the state-of-the-art type of tester. Proper selection of a piece of test equipment, especially automatic test equipment can only be made with a careful study and analysis of many criteria and I'm going to present only a few which should be considered.

Don't overestimate or underestimate the abilities of your technician. I think in general there is a tendency to underestimate their abilities. There's a complex interaction between all of these considerations. For example, the number of units in complexity may have a functional relationship such as shown on the right. It's not quite that simple, however. You can't really have one curve separating automation and manual like that.

You really have a whole family of curves. And so there is a very, very complex functional relationship between all of these items. Cost, we've already covered.

Most importantly is your particular application. The application at the depot obviously is not the same as the factory who is probably in mass production. A depot has low workloads and know if the unit is going to be bad when you get it. A company is probably turning out hundreds of thousands a day, possibly, and most of them are probably good. So to have the same test equipment do the same job for both companies is probably inappropriate.

In conclusion, I wish I had a formula that we could put weights on all these things and plug it into and it comes out with a manufacturer's part number. I don't have that.

In general, the simplest approach is usually the best. If it comes down to a tossup between two methods of testing of fault isolation, generally speaking, the simplest approach is the best approach.

McHALE-NAVY: I might add on the CAINS program which I'm familiar with, we're now into the seventh year of the program and we're introducing the ATE now.

DELANY-DRAPER: Can you tell me whether you have an input to the Air Force modular automatic test equipment programmed whether it's complementary to what

you see as the downstream needs of the inertial equipment repair and overhaul facility?

ROBINSON-AGMC: I am familiar with the program. I have my doubts. I'm very hopeful is about all I can say. I haven't really seen enough to really make any personal judgments.

DELANEY-DRAPER: Are you identifying certain inertial test requirements as sort of baseline inputs to this foe or do you have any actual role vis-a-vis the program itself?

ROBINSON-AGMC: No, sir.

McHALE-NAVY: Thank you, Denny. Next we have Dave Petry from AGMC.

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TOPIC: DIAGNOSTIC SOFTWARE FAULT INSERTION

DISCUSSION:
1. VALIDATION/VERIFICATION
2. AN EVALUATION OF THE SOFTWARE EFFORT
3. PROCEDURES FOR SELECTION AND INSERTION

LESSONS LEARNED:
1. TYPES OF FAULTS TO BE INSERTED
2. TEST POINTS
3. CORRECTIVE ACTIONS TO BE TAKEN

PETRY-AGMC: I'm Dave Petry from AGMC and we're going to discuss automatic test equipment again.

This probelm is one of proving the software package that is being delivered to you from the contractor.

The current regulations, very recent changes, require now that fault insertion be done in the unit under test during validation and verification to prove the diagnostic capabilities of that piece of software. This would be done in much the same manner as a QC program would verify the resistance of a batch of resistors.

The evaluation of this software support effort becomes rather complex whenever you have to determine what fault you are going to insert in the unit under test. What components should be faulted, which ones fail the most, who is going to do it, when they are going to do it and what their performance criteria have to be. These procedures have to be defined prior to work being done in the software area. You can't write the program and then determine later you're going to insert fault to see whether it works because it's just not going to detect the faults.

Many of these faults that are inserted -- we've got a program now that we're having some problems with in this case, when you inswert the faults at a particular point, the question becomes, well, the program will print out several items to be removed and replaced and then you have to determine whether or not this particular area was the actual one that was faulted.

If you have a lot of logic circuitry and you're grounding an input gate or something like that, how does that fault propogate through the circuitry? The use of intermediate test points are not always available and that propogation is affected there also. But probably most important of all, whenever you get down to the final thing is whether or not or how are you going to correct those faults that you did not detect?

And that is really the big thing that no one pays any attention to when a statement of work is written and when the contract is signed. They figure that their equipment is going to work and it always does after a fashion.

McHALE-NAVY: Any questions?

THOMAS-SASO: I'd like to make a comment on No. 2. When I was back at ASD Aeronatical System Division in the PRAM program office, we pulled an audit on inertial navigation systems on that form of an aircraft to see how many of the throwaway items were good. We found out that 50 percent of them that they were removing, these were Cordwood modules, were good, 50 percent. Our lesson learned there was there wasn't adequate test points for the technicians to determine which modules was bad, some were more serious, so consequently as many as three could be thrown away to find the one bad one out of three.

PETRY-AGMC: Yes, with automatic testing, you would always like to isolate it down to one component and say that's it. But very seldom are you able to get less than three, four, five components. And your diagnostic message printed out on a printer generally indicates replace those. They try to place those in the order of probability of failure, but it's not always that case.

THOMAS-SASO: Well, the problem here was instead of throwing away $300 worth, we were throwing away $1,000 worth to get rid of $300 worth.

UNKNOWN: We had a problem too with this automatic test equipment. Some parts had test amount of components for the sake of speed and for (unclear) And to put a new card in, it still doesn't work and we found that we had to go down to the component itself that was mounted on the base. There was not enough test points brought out, so I think they should address that, too.

HARRIS-?: Are you saing that the type of faults that you are going to insert for the validation of software has to be declared before the programs are even written?

PETRY-AGMC: Yes.

HARRIS-?: I disagree with you.

PETRY-AGMC: Dependent upon the unit under test

that is being tested and the use to which that circuitry is going to be put, you can make some determinations as to what kind of failures you are going to see in actual usage. You can make a determination as to whether capactitors are generally short or over, whether diodes are short or over, those type of decisions and from that distribution then you can pick your faults.

Now, the best way to do that is through an analysis of the circuit and fault the areas that should fail first and hopefully in a manner in which they will fail under usage. You cannot cover every condition on a piece of automatic test equipment.

McHALE-NAVY: We'll take one more question here.

SERNAC-AGMC: You know, from my experience at least with three or four sets of depot automatic equipment, I think it's a waste of time, effort and money to build a piece of test equipment to tell me that Module A or Module B or Module C is faulty. You can't do it -- it won't work. But I do think the equipment ought to isolate and identify a malfunction, utilize the technician skills and break your testing sequence down so that you know what phase of the circuitry is being isolated or where the problem has to be. If your testing is broken down into steps, you can say this function is failing and you can now look back at what

that function does and you can look at the seven or eight modules that are in that function and it boils down to the old switchy-swappy technique and your engineers will do it, your technicians will do it, so you might as well save your time and save your money and quit trying to say that this equipment will fault isolate the 95 percent probability to subject module. It doesn't work, in my opinion.

McHALE-NAVY: Marv Brown next. Thank you, Dave.

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<u>TOPIC:</u> USE OF CIRCULAR ERROR PROBABILITY (CEP) FOR PERFOMRANCE EVALUATION ON A SINGLE FLIGHT

<u>DISCUSSION:</u> SINCE THE FIELD MUST EVALUATE INS PERFORMANCE AFTER EACH FLIGHT, THE HABIT HAS BEEN TO USE THE SPECIFIED CEP AS A MAXIMUM RADIAL ERROR FOR SINGLE FLIGHTS. THIS RESULTS IN INTERMEDIATE AND/OR DEPOT REPAIR ACTIONS ON GOOD SYSTEMS AND DEGRADES ABILITY TO SUPPORT WEAPON SYSTEMS.

<u>LESSONS LEARNED:</u> CEP IS A MEASURE OF THE PERFORMANCE CHARACTERISTIC OF A STATISTICAL SAMPLE. ENSURE THAT REALISTIC CRITERIA FOR SINGLE FLIGHTS ARE ESTABLISHED.

F-15 (LN-13) ACCEPTANCE CRITERIA FOR NEW AIRCRAFT

<u>REJECT</u> (1) IF ANY FLIGHT EXCEEDS 7.65 NM/HR
(2) IF AVERAGE OF ALL FLIGHTS $\geq$ 5.1 NM/HR

<u>ACCEPT</u> (1) IF FIRST FLIGHT $\leq$ 2.0 NM/HR <u>AND</u> NO SUBSEQUENT FLIGHT EXCEEDS 7.65 NM/HR

(2) IF AVERAGE OF ALL FLIGHTS $<$ 5.1 NM/HR

<u>NOTE</u> ACTUAL NUMBER OF ACCEPTANCE FLIGHTS IS VARIABLE DPENDING ON OTHER SUB-SYSTEM PERFORMANCE.

F - 15 INS (LN-31) FIELD PERFORMANCE CRITERIA

| TYPE ALIGNMENT | GYRO COMPASS | STORED HEADING | BATH |
|---|---|---|---|
| SPECIFIED CEP | 3NM/HR | 5NM/HR | 10NM/HR |
| RADIAL ERROR FOR SINGLE FLIGHTS | 7.6NM/HR | 12.7NM/HR | 26NM/HR |
| RADIAL ERROR AFTER EACH OF 3 SUCCESSIVE FLIGHTS | 3NM/HR | 5NM/HR | 10NM/HR |

BROWN-ASD: I'm Marv Brown from Aeronautical Systems Division. I seem to have a blank screen. There we go.

Use of CEP for performance criteria on single flights has caused a lot of problems in the past, in fact on most systems that I am aware of. I think I'll just let you read that because it says it as well as I can say it, because I wrote it.

So the problem then is to establish realistic criteria for the air crew member to use in faulting a system at the end of a flight. And CEP is not the number. Next line.

I'm going to give you some information on how the F-15 system approached the problem and applied the lesson learned.

There has to be a thread between or from the factory to the field. The acceptance criteria we establish for acceptance of the system in flight test

had to be considered if we were to expect the systems to perform to the CEP requirement of the spec, and in-flight test, since you have a limited number of flights that you are going to be flying in order to buy off an aircraft obviously you cannot use the CEP number.

Sometimes a flight may be sold off in one or two flights and then because of other avionic malfunctions you may fly a larger number of flights to sell off an aircraft.

And so we recognized early in the program that we had to establish some realistic criteria for acceptance of the aircraft and these are the criteria that we accept, that we established.

If any flight exceeds 7.65 nautical miles per hour, we would reject that system on that flight. If we had more than one flight, then we would accept the system only if the average was -- looks like I got something backwards there -- oh, yes, I skipped to the accept.

The reject criteria we would reject if all the flights averaged greater than 5.1. By the way, you might want to know what our CEP requirement was that these relate to. Our CEP requirement was for a 2 mile an hour CEP system. And actually the Air Force buys to a 3 nautical mile per hour CEP.

Now, on the first flight, if we come in with less than or equal to 2 nautical miles per hour and if no subsequent flight went over the magic 7.65, then we had to do no other tracking on that system. It is a good system and we buy it. Also the average of all the flights had to be less than 5.1 nautical miles per hour. So actually there's about three requirements in those two. And again the number of acceptance flights is variable depending on other avionics that's being bought. Next line.

Now, on the F-15 program, we have different specs for the different types of alignments. We have a gyro compass alignment where the specified CEP is 3 miles per hour. And stored heading alignment, we have 5 miles per hour and bath, which is the best available true heading alignment,we have a 10-mile-an-hour CEP. So we establish for the gyro compass for the pilots in the field a 7.6 nautical mile per hour radial error for a given flight. This represents 2 sigma I believe, assuming a rating and distribution.

Stored heading requirement on a single flight was 12.7 miles and for best available true hearing 26 miles. Now the radial error after each of three successive flights must come in at 3 nautical miles. In other words, we go back to the spec, if you will notice those numbers.

As a result of this, we've had probably fewer false write-ups and maintenance actions as a result of false write-ups on the F-15 program as probobaly on any other program I know of. It also, because we have established these criteria and put them into the tech orders, it forces the maintenance people to do the tracking necessary to have a history of all of these systems. That's it.

McHALE-NAVY: Marv, is there a specific time of alignment associated with each of these numbers?

BROWN-ASD: Yes, the specific time required for alignment on the gyro compass is ten minutes and we do that in about 9.6 under temperatures of zero degrees and up.

Stored heading alignment for zero degrees and up is 3 minutes and the bath is the same.

HYMAS-CIGTF: How did you compute the performance for a given flight? Do you use end point, total time, straight line fit or do you take the steepest slope over what you get? What does that number mean?

BROWN-ASD: All right. What that number means is the radial error rate. In other words, it's the flying time or actually the time that the system is in navigate divided by the terminal error, which is about the best you can do.

HYMAS-CIGTF: So terminal error divided by total flight?

BROWN-ASD: Okay, I'm sorry. I switched it.

UNKNOWN: Marv, who computes that 5.1 nautical mile an hour as a limiter. Who determineds the statistic?

BROWN-ASD: Okay. We establish the requirements obviously statistically. Now, the requirements are written into the TO's so that at the end of a flight if the pilot feels that he has a system that is not performing to spec then he writes it up based on a given terminal eror and if it satisfies the criteria and it's a fault, then it's a valid write-up. If it isn't, it's written off as a CND.

UNKNOWN: You said the average of all flights being 5.1. Who takes all that data and then averages by the number of flights. Who performs that function?

BROWN-ASD: Okay. The pilot obviously would not be able to know how many flights had been written or whether it had been written up on the previous flight so he would use first criteria if it fits that, then he'd write it up. But the maintenanceman when he looks at the history of the previous flights and then if it satisfies that requirement then it would be a pull.

UNKNOWN: He's computing it. It's interesting. So this maintenanceman has to have some appreciation of

this mean radial error or this average radial error, though in fact it's averaged over flights, and that may be one of the problems with regard to people pulling out good systems that they don't understand the difference between -- or they don't understand what CEP does though they evidently understand what mean radial is.

And we're certainly not going to turn around now; but had we specced navigation systems in terms of mean radial error, it might have been something that's more readily understandable on the part of an operator.

BROWN-ASD: Well, I understand what you're saying. I don't foresee any future procurements where we don't spec it by CEP. I think that's going to be continued. But at the same time we do have to realize that operators of equipment have no knowledge at all of the CEP requirements or should really have no knowledge and if we don't specify to them in the TO's what they can expect on a given flight, they're going to find the CEP number somewhere and that's what they're going to use as their figure of merit and that's the lesson to be learned is that we must in our TO's specify realistic criteria for a single flight and this is what we have done on the F-15.

McHALE-HAVY: Okay. In the center here.

NEIWOOD-SINGER: I'd like to say "amen" to that

procedure. It's been my experience also that a very large percentage of removals are because of this very fact pilots (blank) individual flight performance, which as you point out is unrealistic. If I'm going to put in a plug for my presentation at the end of this week, I'm going to address that thing and show you some data where it apparently implies that there's a direct relationship between CEP and MTBMA. So unless something like this happens, unless it's forced into the TO's, you're not going to see any inertial system whose reliability or MTBMA which a lot of people equate is going to be any different than what you've seen up until now.

BROWN-ASD: I agree with that.

McHALE-NAVY: One more question up there.

THOMAS-SADO: Are you able to get TAC to keep these kind of records? I worked a lot with TAC and when I worked with them, if they kept something like this, it had to be in official notebooks that when the IG came around they couldn't find them. In talking to some of the TAC guys about the concepts they have of the F-15, I understand that they don't have a specialized INS guy that does it. It could be anybody that goes out and pulls the box, the guy that's supposed to remove the tires, the engine. So my question is are you able to get TAC to

keep records like that even if you put it in the tech order?

BROWN -ASD: Yes. It's actually very simple how you can do that and that is when you put it in the TO, it becomes a requirement and there is a history card on every IMU that goes into the aircraft and the maintenance people do maintain those cards and they have to because of just that reason, it is in the TO.

McHALE-NAVY: The Navy would like to have a couple hundred of those cards.

ROWAN: (DID NOT USE MIKE)

BROWN-ASD: George, that would be very nice to do, I suppose, if it were possible, but when you consider the question that Neil just raised, it has been pretty difficult until now just to maintain a terminal error hiostory on the IMU,so that would be impossible to do in a field operation.

McHALE-NAVY: One smart pilot did that in the RA5C and he won the bombing derby three years in a row.

BROWN-ASK: When you have a few small number of systems, you might be able to manage that.

McHALE-NAVY: Next, Al Brann. Thank you, Marv.

NIEWOOD-SINGER: One more comment on that question of keeping records. We recognize that keeping records of NAP performance might be difficult, so we have addressed this problem especially because we have

on the F-16 warranty responsibility and we're very anxious to avoid false pull because of all the damage it does. So into our system we've incorporated in the software the ability to call up on the flight control NAFPAL, the NAB error rate for the three previous valid flights. Now, I say valid, but that addresses the other question, If there were any in-flight corrections then that data is ignored. We take terminal error. So I think we have partially solved that problem. At least we hope we have.

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TOPIC: EFFECT OF ON/OFF CYCLING ON RELIABILITY PREDICTIONS

DISCUSSION: FIELD EXPERIENCE WITH BOTH COMMERCIAL AND MILITARY SYSTEMS HAS SHOWN POOR CORRELATION WITH MIL-HDBK-217B RELIABILITY PREDICTIONS. A MAJOR CONTRIBUTING FACTOR IS THE EFFECT OF ON/OFF CYCLING (OR LENGTH OF ON TIME) DURING FIELD OPERATION.

LITTON RELIABILITY RECENT CONDUCTED A STUDY WHICH EVALUATED THE EFFECT OF ON/OFF CYCLING ON ELECTRONICS RELIABILITY. THE STUDY CONCLUDED THAT THE RATIO OF OBSERVED TO PREDICTED FAILURE RATE WITH ALL FACTORS, EXCEPT ON/OFF CYCLING CONSTANT, IS GIVEN APPROXIMATELY BY THE EXPRESSION:

$$K = \frac{3}{\sqrt{T}}$$

WHERE T IS THE LENGTH OF THE OPERATING CYCLE

LESSONS LEARNED: (1) PREDICTIONS OF FIELD RELIABILITY IN ACCORDANCE WITH MIL-HDBK-217B DO NOT CORRELATE WELL WITH ACTUAL EXPERIENCE.
(2) THIS COMPLICATES LOGISTIC SUPPORT PLANNING
(3) KNOWLEDGE OF OPERATIONAL ON/OFF CYLING REQUIREMENTS PERMITS A MORE ACCURATE PREDICTION OF FIELD RELIABILITY.

BRANN-LITTON: As most of you are aware, at the front end of a program, we do a reliability prediction and over the last couple of years that's become very standardized to be the MIL-HDBK-217B. This is normally a contract requirement.

And in doing the prediction, thereare factors of the environment the aircraft goes into; inhabitated, uninhabited; there are factors for the quality level of parts. You go through the whole system and you get a bottom line number that's a prediction.

One of the things that we feel is significantly missing from the algorisms in these predictions, and one of the factors that I think explains some of the differences in performance and systems between military and commercial as an example, which was discussed this morning, is the effective on/off cyling.

So what we did we had some equipment that was used,the identical same equipment by configuration, in different aircraft that had different on/off cycling times. Aircraft that had early warning type missions as opposed to fighter and also ASW in the case of the CAIN system in the Navy inventory.

Then we had ships control systems out in the DD963 destroyers and we had a system, the Army system, that was discussed earlier today, that had run in 2-1/2,

2 hour type on in some missions and had also run in laboratory demonstration station tests with 500 hour ont-times.

So we took all this data and we analyzed it and the bottom line that we came to, agrees very closely with a report by RADC, I think it was done by TRW for RADC. And effectively what it says is that each on/off cycle is equivalent to somewhere between four and twelve hours of on time.

Another way of looking at that is that MIL-HDBK217B prediction basically is for a ten-hour mission. That's what we found to be true. So if you use MIL-HDBK-217B for a commercial inertial system, for example, you should be right on the nickel if you have all the other factors for temperature and environment.

But if you're going to use it for a fighter aircraft, you had to derate the number that you get to take into consideration the fact that it's turned on and off three times during that ten hour period, instead of just once.

The physical factors I think are relatively obvious when you first turn on this turn-on is to consider everything has to come up to temperature so there's obviously thermal coefficients of expansion and contraction and all the semi-conductors and all

magnetics and those can be understood and designed around as much as possible, but never eliminated.

So our lesson learned from this is that on/off cycling really does have an important role in the reliability of equipment and when doing predictions for equipment especially those used in the shorter missions, it should be taken into account. And I shouldn't say especially -- it should be taken into account when you want to plug a system that has a short on/off cycle into a longer range or you'll overspirit.

We have equipment that's in fighers that we put into transport type aircraft, identical configuration and the MTBF will double and triple in that environment. Some of that is due to better cooling air, some of that's due to a lot less vibration, but there's a part of it that's due to on/off cycling and I think it's quantifiable. We've come up with a number that we use. Any questions or discussions?

LOGUS-ASD: It's more of a comment and the comment would be "amen." In fact NASA produced a report on the space shuttle and analyzing just the subject of reliability and part of it was the on/off cycle and they did show what you get in the way of an on/off cycle and the effect and the equations that were in there and I believe that the NASA report references still a previous

from -- I believe Draper Lab -- on the equations to be used. They even went one step further, it was a little more difficult for them to do it with some of the equipment, but on others they could, and that was aging process which also had to be considered.

BRANN-LITTON: A dormancy.

LOGUS-ASD: Yes, that's correct. But not dormancy in the sense of a turn-on where you have it available for 90 days or 120 or whatever, but aging in the sense that when you buy a piece of equipment and own it out to a period of years, that equipment even if you don't turn it on, there's going to be material creep that will occur, shrinkage, changes in the content.

BRANN-LITTON: I'd like to make a comment about that. We have a rule at Litton at receiving inspection, and that is if the date code is older than two years old, you can't let the material in. The reason being that on a lot of the programs today, you have a literal dormancy requirement, like a cruise missile program for example, and there is a finite failure rate that you use for that period of the mission profile.

So since we had enough of that kind of thing, we just applied it across the board. Now, it's shorter on things like rubber material and grommets that definitely have a wear-out period. But in general, like semi-

conductors, IC's, hybrids, etc., it's two years; it can't come in over two years.

And then we have another aging requirement. It can't stay in stores. We don't usually have that problem, we try to keep inventory low like everyone else, but as far as the stuff coming in the back door, we do have that kind of requirement.

Incidentally, we shared this with RADC, wrote RADC a letter formally, and requested that they consider that MIL-HDBL-217B require that on/off cycling be taken into consideration. We volunteered our factor T over the square root of 3 which we think is the right number. I think it correlates well with the previous studies. I'd like to see them make that change myself.

LOGUS-ASD: We've actually used the numbers or similar numbers or ratios of numbers similar to the one that were produced by NASA and in looking at an airplane, fighter type airplane, with much shorter flight time, and it correlates very close with what we expect we would see. A dramatic reduction in reliability.

McHALE-NAVY: Okay. One more question in the center aisle.

UNKNOWN: What is RADC, Al? You're using acronyms.

BRANN-LITTON: Romear Development Center. They

control 217B.

WUERTH-AUTONETICS: When we ran a study on Minuteman which where we had some special data, I've got a special report if somebody wants to look on it, but it extremely supports this point. But on the other hand, going back to Minuteman I, we had a life degredation written into our derating stuff and all that, you know. We tookall this into account in our Minuteman I parts and a few years ago we got hold of some of the old Minuteman I boards. This was not failure rate; this was in performance degredation. We got those boards torn apart, measured them and we couldn't find any change from the original parts.

BRANN-LITTON: The dormancy studies are far from conclusive because nobody has decided to store things for ten years to do a real lab test. But Appolo has generated a lot of data and as you say Minuteman. It's interesting no one seems to disagree with the concept, and yet we still haven't got all the changes made to the predictions techniques and so forth. But maybe we'll be successful since there seems to be such concurrence.

McHALE: Nobody's willing to pay for all that good hardware on the shelf. One more question.

SHIPP: Is your report available? Is it

written up, the study?

BRANN-LITTON: The study will be at the spring IEEE R&M symposium. If anybody wants a copy, you can get hold of me through the smposium here and I can send you an advance copy of it. The author is a man named George Kajowski who works at Litton and he'll be presenting it at the spring IEEE R&M symposium.

McHALE-HAVY: Thank you, Al. Next we'll have Tom Rogers, AGMC.

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TOPIC: PROGRAMMABLE THERMISTOR CALIBRATION SYSTEM

DISCUSSION: (1) FORMER SYSTEM SLOW AND CUMBERSOME. (2) PRESENT SYSTEM FAST AND ORGANIZED. (3) PROPOSED SYSTEM FAST, ORGANIZED AND WITH A GREATER FLEXIBILITY.

LESSONS LEARNED: THERMISTORS CAN BE CALIBRATED IN LESS TIME, WITH GREATER ACCURACY, BY USING A PROGRAMMABLE UNIT.

ROGERS-AGMC: Programmable thermistor calibration systems. At AGMC, we had a problem with calibrating thermistors. It's a long dragged-out process of reading temperature by resistance, sometimes takes up to two and a half hours average just to calibrate one thermistor.

So we came up and started to check into a programmable system. Our former system we had here used about 14 pieces of equipment to calibrate one little, tiny thermistor.

Now a thermistor looks an awful lot like a thermocouple, only it's measuring in resistance. There's a lot of twiddling around with dials, knobs, you have to take readings, you have to watch galvanometers with lining them up with your eyeball which creates more errors. At the same time you've to to be changing temperatures on your temperature baths. You have to write down your readings from a Wheatstone bridge or from using a Rubicon bridge or something of that type and after you get all of your readings down, you have to calculate them all out using a calculator, you write it all out by hand for a secretary to type it all up for you when you're done, and all these things created errors.

So we started looking into a system -- you can see all the odds and ends we had and all the knobs we had to twiddle around with and all the galvanometers to read and night switches down at the bottom and decades. There was a lot of things to do. So we checked into a system and came up with a new system.

Over here on my right, you see a tinning bath, mounted on that you have a standard platinum thermometer. In the center up here at the top is our controlling agent and down here we have our typewriter input. That's all the instruments we're using now.

The old one you see over here on the other side.

The operator now all he has to do is type in his name, the date, the type of thermistor he's checking. Type in the ranges he wants to check in, wants to read out on his temperatures and put down the number of ranges he wants to do and he can do -- on the other system, you could check one thermistor at a time -- here we can do up as high as 18 at one time. We've reduced our time from 2.5 hours to .11 hour. Quite a reduction in time and cost.

Now, after we got this all laid out and designed and it works fine and everything. This is a turnkey type system here. After you put everything in, you just lock it in and it goes ahead and works. We found out that's nice, but we had problems. We wanted to do more things with it.

We are having it redesigned right now. A new model is being made on it. We're going out on it, having it written in Fourtram for which this one was locked in, we couldn't make any changes. We will be able to now calibrate, we had to reduce the number of thermistors we're going to calibrate from 18 down to 8. We found out we couldn't calibrate that many at one time anyway because we didn't have that many in. Planning too far ahead.

But one thing we could do now. Before, we had to

use the same temperature for all thermistors on the mount at one time. On this new system we have 20 different temperatures for eight different thermistors at one time and lock it in and on the other one we found that our tinning bath would change temperatures so fast that we couldn't get a true reading. We're going to control the temperature of the tinning bath also by using the computer and doing this, we can even use the same system for calibrating thermometers.

Now, who wants to calibrate thermometers. It's another slow dragged-out job and you say, well, they're always good anyway, but sometimes you don't know that and they do have to be checked. So now we can command our temperature bath to go to a certain temperature and hold and we can check the thermometer. We can type in the reading on the thermometer and go to the next stage and on.

Another dull job we had that grew into the new system was decade boxes. Resistance decade boxes sometimes have four and five switches on them, each switch has about ten positions. A man has to turn the swtich to do just about the same type reading we had on the old system there, write down his information, do it all by hand, and it was a slow job.

On our new one coming up now, which of course we don't have a picture on it -- it's being built -- we'll

be able to turn the swtich, command a reading. The computer will record the reading and give us our data all printed out at the end. We've learned from this that we can take a simple job like thermistor calibration and do it using a programmable system, which some people say cost a lot of money, but we save money and time. Any questions?

McHALE-NAVY: Questions? Okay, thank you, Tom. Okay, Ill turn the podium over now to Joe.

KENNEDY-AGMC: I have a note here. Everybody is doing a real great job of identifying themselves when talking into the mike, but people are having difficulty hearing people, so either talk louder or put the mike closer to your mouth when you are speaking so everybody can hear you.

I have one comment on the on/off cycle that I thought was kind of interesting. Everybody thinks that on/off cycling is important in terms of reliability so I just can't quite understand why we couldn't get an on/off cycle in the FT spec.

The next item we have is Mr. Al Taschner from the Navy.

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TOPIC: NI-CAD BATTERY SCHEDULED MAINTENANCE

DISCUSSION: THE AN/ASN-92V (LN-15) CONTAINS A NI-CAD BATTERY FOR EMERGENCY POWER REQUIREMENTS. IN ORDER TO ENSURE THAT THE BATTERY IS IN A FULL CHARGE CONDITION IT IS REMOVED FROM THE AIRCRAFT EVERY 56 DAYS FOR A CHECK, TEST AND RECHARGING, IF NECESSARY.

LESSONS LEARNED: INITIALLY THE 56 DAY REMOVAL WAS ACCOMPLISHED BY REMOVING THE BATTERY BASED ON THE AIRCRAFT'S 56 DAY MAINTENANCE CYCLE. HOWEVER, IT WAS DISCOVERED THAT THERE WAS A HIGH RATE OF CANNIBALIZATION OF POWER SUPPLY ASSEMBLIES ( THE NEXT HIGHER ASSEMBLY OF THE BATTERY) AND THAT SEVERAL BATTERIES WERE NOT BEING CHECKED EVERY 56 DAYS. THE SOLUTION WAS TO ADD A BATTERY HISTORY CARD DECAL TO THE BATTERY COVER, SHOWING WHEN THE BATTERY WAS NEXT DUE FOR A RECHARGING AND REQUIRING ALL PERSONNEL TO INSPECT THIS DECAL PRIOR TO INSTALLING A BATTERY IN AN AIRCRAFT TO INSURE THAT IT WAS NOT OVERDUE FOR CHARGING.

TASCHNER-NAVY: Al Taschner from the Naval Air Rework Facility, North Island, San Diego, California.

The topic I want to bring up is the CAINS NI-CAD battery we use in the LN-15 inertial system. Discussion on the battery was that due to the various aircraft that we have using the battery, five different types of configurations and the mechanizations we had for applying emergency power whether you're on the ground or in the air and some of the problems we had with the operator powering down inertial systems at the end of a flight, we ended up with quite a few batteries out in the field that really didn't have the capability of supplying emergency power when we needed it.

So we instituted a 56-day check which coincided with a major aircarft 56-day check in order to cut down any scheduled maintenance we were creating whereby the battery would be removed, checked and test and recharged.

What we find out what we thought really was going to solve the problem did not solve the problem becuase on the other hand the power supply which the battery is an assembly of was undergoing a high cannibalization rate out in the field. Shortage of power supplies and supply system, if they had an aircraft that was down for another box and power supply was good and they could put it in another airplane and take it out and get one more airplane up in the air.

What this would do is get batteries jumping from airplane to airplane and it would work out real nice if they would miss the 56-day check. And then when you need the battery for emergency power and it wasn't any good anymore.

So what we did to solve the problem that we should have solved right the first time was we put a battery history decal on it, specifying when the battery was last charged, when it was due for charging and instituted a requirement in the tech order that whenever a power supply or battery is installed in an airplane, that the maintenance personnel are to inspect the history

decal card to see if it was past due or within a short time frame of the 56-day check and charge cycle. If it was, then he wasn't authorized to put that unit in an airplane. Had to send it in to the intermediate level to get charged. And I guess the biggest solution is now we are getting rid of the battery totally in any other inertial systems that the Navy buys.

BROWN-ASD: Did you have a trickle charge on that battery?

TASCHNER-NAVY: There is a trickle charge on that battery, however the improper turning off of the system was occurring essentially on certain flights and the trickle charge wasn't enough to bring it back up to full charge in just one or two flights.

KENNEDY-AGMC: The next topic will be presented by Dennis Foley of AGMC.

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TOPIC: REPAIR AND REFURBISHMENT OF HIGH VALUE THROW AWAY INERTIAL COMPONENTS (RETAP)

DISCUSSION: MANY HIGH VALUE INERTIAL COMPONENTS ARE CODED "REPAIR BY REPLACEMENT" (THROW AWAY), OFTEN BECAUSE OF THE DIFFICULTY INVOLVED IN RESTORING THEM TO USEFUL CONDITION. SINCE THE ESTABLISHMENT OF THE METHODS LAB AT AGMC IN 1967, TECHNIQUES HAVE BEEN DEVELOPED TO ECONOMICALLY RESTORE A LARGE VARIETY OF THROW AWAY PARTS TO SERVICEABLE CONDITION. THIS HAS RESULTED IN LARGE SAVINGS TO THE GOVERNMENT AND HAS ALSO RESULTED IN THE AVOIDANCE OF MANY WORK STOPPAGES AND SCHEDULE SLIPPAGES DUE TO THE NON-AVAILABILITY OF NEW COMPONENTS.

LESSONS LEARNED: 1. ALL HIGH VALUE THROW AWAY COMPONENTS SHOULD BE EVALUATED FOR POSSIBLE REPAIR/REFURBISHMENT. 2. ORGANIZED APPROACH, SUCH AS THE METHODS LAB, IS COST EFFECTIVE. INNOVATIVE, IMAGINATIVE METHODS SPECIALISTS CAN OFTEN DEVELOP ECONOMICAL REPAIR TECHNIQUES WHERE OTHERS HAVE FAILED.

FOLEY-AGMC: If you want to read the above chart, I believe it's self-explanatory. I believe this is a new subject at this conference, refurbishment of high value parts and components. Actually, this has been sort of a multi-million dollar operation for the methods lab since 1967.

We go to show two examples of refurbishment. This is the first example. This is the 16-peg assembly. It consists of two end housings, a float and the main housing. This came to us several years ago and it turned out to be a three-fold refurbishment project. Our scale is backwards, but the approximate size of the 16-peg housing assembly is 2 inches by 1-7/16 in diameter.

This is also the same assembly showing the tool that is used to remove the clamping ring. Initially, the clamping ring used to be machined off. We developed an electromechanical process to remove the clamping ring and so then we were able to reuse them. The second part of the project was to remove the end housing or the main housing which was done in the method that was dangerous to the suspension. It used to cause leakage in the suspension,

oh, about 10 percent of the time. We devised a new tool that secured the assembly in a different area preventing this damage.

The third part of the project. This is the meat of the overall project where assemblies that were rejected because of leakage between the suspension of the microsin had to be replaced. The value of the end housing at that time was $1400. What we did was develop tooling along with a procedure to reassemble the suspension to the microsin, of course using epoxy.

The next slide will how you the tool that was developed for the process. What the tool does is mechanically align the suspension to the microsin. This is a mechanical alignment while the epoxy is in place. Then the fixture is taken over to the console and electrically aligned.

At that point, everything is locked in position, the fixture is removed from the console and placed in an oven for the curing of the epoxy. After one hour of cure, it's removed from the oven and then retested.

This project alone, just the refurbishment of the end housing was worth $239,000 to our cost reduction program.

The next slide will show you a similar project. Now, this is the LN-15 accelerometer restoring amplifier. The amplifier is that little blue package at the end of

the accelerometer. It will show you three views of the accelerometer in the next slide.

The view at the upper left is the ARA as it looks when it's removed from the accelerometer. On the left side of that view and at the bottom you see a black border. That is the shield. The bottom view on the left is the shield removed and the views on the right are the ARA package separated. Now, this ARA is one inch square, it's 7/16ths of an inch high and it contains 53 individual modules. We pay $653 for this and it's part of a throw away item by the contractor. We developed an in-house capability to refurbish the ARA package. In some cases we have to separate the ARA which is shown in the next view.

We have an operation which sets this up in a very shallow solder part and used in conjunction with a lapel induction equipment, we heat the solder part very quickly and separate the unit. As I said, we only find it necessary to open 10 percent of the ARA's. The remaining ARA's are repairable without opening.

The modules that need to be replaced are usually around the outer perimeter.

In this case, the large IC in the center occasionally has to be replaced. That's why we open it. This can be repaired for less than $100, realizing about $550 savings for AGMC. Are there any questions?

Lessons learned. We do and will continue to examine all high value throw away items with the intention of course of refurbishing those wherever possible. The methods lab is an organization that has been set up at AGMC in 1967 and we are just about ten years old this year. It's a cost-effective organization. Parts refurbishment is just a sideline for us. We get into a lot of other areas. Any questions?

LOGUS-ASD: I guess the question I have is, have you, in computing the cost savings, have you looked at all the cost elements that are involved in that, because we in the government look at a cost savings and there are times when we zero out certain dollars because we assume that they are there and we can use them ourselves. The assets of the buildings and the facilities that are around and the test equipment. I guess my question is in computing this cost saving, did you include all the cost elements?

FOLEY-AGMC: If you mean by all the cost elements, we keep a fairly strict account of the hours on these projects. We assign a project number, we assign one or maybe two individuals to the project and he keeps a daily record of his hours spent against that project. We also have a record of the materials that we buy against the project, maybe machining costs, assembly costs and that type of thing. So we keep a fairly accurate cost figure

against the project.

LOGUS-ASD: And the overhead?

FOLEY-AGMC: Well, the overhead is figured, I believe on a cost figure against our labor rate. I believe that figure includes overhead, but I'm not sure.

KENNEDY-AGMC: The overhead is included in the standard rates that we use. Depending on the work center that the work is done in.

LOGUS-ASD: Then I guess the question is, is surely there must have been some kind of analysis that established that this would be a throw away item. Was there any check to see how your analysis compared with theirs?

FOLEY-AGMC: No, there's no analysis from our point of view into that subject. I think in some cases some of these processes may have been developed by the contractor earlier or later on and maybe offered to AGMC.

THOMAS-SASO: Joe, I'd love to comment on this because that A200D accelerometer is on the F-4 platform, it's on the F-111, that accelerometer restroing amplifier. I've seen it in many different configuruations. It happens to be packaged here so they can put it on the accelerometer in the F-4. It's a plug-in card, and out at Hill Air Force Base, they repair it very economically. I don't think there's any trade-offs that were made. I went down to the Naval Air Rework Facility to look at the LN-2, which is

a predecessor to the LN-12. The LN-2 was packaged much cleaner than the LN-12 is. Instead of going forward in the LN-12, which is a follow-on, they retrogressed in the way they packaged things,so I don't think there was any analysis. I think it was just evolutionary cancer.

UNKNOWN -LITTON: They're talking about one of our items. The criteria on that is quite straightforward for the Navy people as they are 10A. It's reliability versus cost and that at that time it was less than $500 and had the reliability required as a throw away item. It was not, it was like you said, there was no analysis really done. It's an AR10A requirement.

McCLANNAN-NAVY: All right. Maybe you'll explain that AR10A for some people.

UNKNOWN-LITTON: AR10A says in good bold pring, right, Oscar. Meet 50,000 hours predicted mean time between failure and also if it costs less than $500, it's automatic throw away. All the CAINS program and other programs the Navy has has that criteria in it.

So we have to remember that criteria was written 10, 12 years ago. We're still using the same one in spite of escalation of costs, so I don't know how valid it still is.

KENNEDY-AGMC: I think the basic problem is that the decision to throw away is made very early in the

program and what Dennis is doing is the same thing where we have actual factual data on cost, our own capability to do it and what the reliability really is. And sometimes this factor changes, skill levels change and it's now cost effective where it was not cost effective early in the program or decided that way because of predicted data.

THOMAS-SASO: The very same designs were repackaged in different configurations on one aircraft as throw away and on another they're not. So I don't see any analysis or logic except to meet the criteria of a particular contract or particular buy.

KENNEDY-AGMC: Al Taschner from the Navy.

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TOPIC: AN/ASN-92(V) CARRIER AIRCRAFT INERTIAL NAVIGATION SYSTEM (CAINS) TECHNICAL NOTES

DISCUSSION: FORMAL COMMUNICATION CHANNELS AND TECHNICAL MANUAL UPDATES INVOLVE LONG TIME DELAYS IN FOWARDING INFORMATION TO CAINS FIELD ACTIVITIES.

LESSONS LEARNED: A SMALL BOOKLET TITLE "AN/ASN-92(V) CAINS TECHNICAL NOTES" IS DISTRIBUTED ON A PERIODIC BASIS TO ALL CAINS USERS. THIS INFORMAL DOCUMENT CONTAINS NUMEROUS AMOUNTS OF INFORMATION THAT HAS PROVEN USEFUL TO FLEET PERSONNEL IN THEIR DAY TO DAY WORK WITH CARRIER AIRCRAFT INERTIAL NAVIGATION SYSTEMS.

TASCHNER: Al Taschner from San Diego, California. This lessons learned is something I'm sure everyone has had a problem with before. It's the problem of getting

up-to-date documentation out into the field to the flight line and to the intermediate level activities that do the repair. You've got changes being cranked into the syste, ECP's, problems that you're trying to correct, and most of this all has to be done through formal communication channels. You have to get your tech manuals updated, out in the field. You got long lead time to get the information to a printer and get it distributed so on the CAINS program we instituted a small pamphlet called CAINS technical notes.

This comes out approximately every two months and it provides a quick and easy channel to get this information out to the user and we send it to everybody we can possibly tie into the program and it's a quick way of getting latest changes out in the field, changes in test procedures, some work-around test procedures until a final test procedure can be solved, particularly with VAST.

IOL, supply information, what their initial outfitting list is, check with supply to make sure they're getting everything they're supposed to get so they can order ahead of time and not find out after the fact that they don't have this item and that item and then they say I should have had ten of them.

I think it's a good vehicle for other programs to look into if you have a problem getting information out into the field and helping the user out.

KENNEDY-AGMC: I'd like to ask somebody from the Air Force comment on that. Bob/ I'm talking about the legality of it, use of it in the Air Force.

BARKER-AGMC: Does that notebook do any change or augmentation of the tech manual in the field?

TASCHNER-NAVY: It's not an official or formal change, but it does the same thing that a formal change does. Once you get the information to the user, he's going to use it and that's what you want to do.

BARKER-AGMC: How do you get away with that? We can't do that in the Air Force. Can you actually implement a new test or an amended test?

TASCHNER-NAVY: Yes.

UNKNOWN: Do you have a system also for quick reaction team, not quick reaction, but other change in TO's, your manual, you got a book out, like RR005-1, right?

TASCHNER-NAVY: Right.

UNKNOWN: This this is really circumventing the system, your own system.

TASCHNER-NAVY: Well, in the rapid action manual changes we have, they have to meet certain financial criteria which puts a restriction on going that route all the time and it's a very low dollar value and it doesn't always work, you can do that.

BROWN-ASD: Wouldn't it be a better idea to

change the dollar value on that to stay within the system?

TASCHNER-NAVY: Well, I assume that when they originally went in to take a look at the dollar value, they had to reach some financial limit whereby they could legalize everything; otherwise you'd have everything going through.

UNKNOWN-AVIONICS: I think -- I'm not an operational type -- but I think you get involved with 66-1 when you tart talking about maintainability of aircraft and when you start trying to do something like that, it won't work because it doesn't fall within the ground rules of that, so it's got to be in the TO, or, if it's not there, they won't use it. That's something something that we have, thank God from SAC from many years ago and we use it all over the place now.

McLANNAN-NAVY: I would say maybe it don't work for the Air Force, but it works for the Navy and we love it.

UNKNOWN-AVIONICS: I was in the Navy at one time and it probably could work for the Navy because the Navy approaches things a little differently. They didn't adopt the 66-1.

KENNEDY-AGMC: Are you saying they don't follow the TO?

UNKNOWN-AVIONICS: No, not always.

KENNEDY-AGMC: Now we get to Dick Gidlow.

TOPIC: REQUIREMENT TO PROVIDE A SUSTAINING EFFORT FOR TECHNICAL ORDER UPDATING.

DISCUSSION: TECHNICAL ORDERS (TOs) ARE USUALLY PREPARED FROM TECHNICAL DATA IN USE BY THE MANUFACTUING COMPANY DURING AN EARLY PHASE OF PRODUCTION.

LESSONS LEARNED: THE CONTRACTOR MAKES MANY CHANGES IN HIS MANUFACTURING AND REPAIR LINES THAT ARE DIRECTLY APPLICABLE TO IMPROVING THE ORGANIC PROCESSING OF THAT SAME HARDWARE IN THE GOVERNMENT'S SUPPORT FACILITIES. A REQUIREMENT EXISTS TO HAVE CONTRACTOR PROCESS CHANGES REVIEWED FOR INCLUSION INTO TOs ON A REGULAR BASIS (i.e. EVERY SIX MONTHS).

GIDLOW-S-KD: We can take time to read it here. And basically what we're talking about is the way that tech orders are prepared and delivered into the using agencies. The tech orders themselves are generally the result of data that's available from production processes and the tech orders themselves are delivered early in the program and therefore the data that they are constructed from is data that was used early in the program.

As a production program evolved, we find that many process changes take place in the production line which are improvements in the method of putting that equipment through a given line. And many of them are applicable into the overhaul tech orders especially and they are definite improvements in the processing of that equipment.

The things that I'm talking about are not

necessarily confined to, but some of the examples are improved cleaning solvents and cleaning processes, cleaning equipment which yields a better instrument. We're talking about test procedures that are in-process test procedures and they shortcut the time of processing a piece of equipment through a given operation and in effect what they do is these are really the improvements that take place in a production line over a period of time and the lessons which are learned in the production line are not necessarily delivered on any regular basis or even on any required basis into the tech manuals that are being used at the organic levels of maintenance.

I guess, you know, that the lesson that we learned is that we don't always apply all of the lessons that we really do learn and it's not just in tech orders, but it looks like many things like the CEP requirements, which people have been talking about for ten years, but haven't done anything about it. I think there are a number of lessons which have really been learned but have never been applied and in tech data this is one of the areas where we can really cut costs is by getting improvements that are known and having the requirements to put those improvements into the tech order.

The voluntary system right now is the SO-22 in the Air Force. It's not strictly voluntary, there

are some requirements. There are some contractual requirements to put those changes into an SO-22 format, but in general there's no real requirement to put those processes, even for the government to use those improved processes. Any comments?

LOGUS-ASD: Are you volunteering this for nothing to the Air Force or do we have to pay for these?

GIDLOW-S-KD: No. You're probably going to have to pay for it because we just can't monitor all changes that really take place in a line over a period of time and decipher which ones really apply to the exact tech data that may be current.

LOGUS-ASD: Where do we get the money?

GIDLOW-S-KD: Gosh, if you can't afford improvements --

LOGUS-ASD: I didn't say we can't afford them. Money has to be allocated and lined up over a period of time. I'm not arguing the point

(TWO QUESTIONS DID NOT RECORD.)

UNKNOWN-LITTON: Being associated with that particular problem quite a bit, too, logistics. You're covering a fact there on we, as manufacturers, I have found and it was brought up here just now,the military environment generates a need for updating, too. I think I would like to add to what you are saying there, not

only to the manufacturers who have a hand in this, but also that the military environment get involved directly with this also, so that we can all correlate this. Of course the Navy puts out the UR's which we occasionally get back in our tech areas to update manuals. Sometimes we don't even get those.

GIDLOW-S-KD:And the processes for getting these changes out to the people who use them are very, very slow very often.

LOGUS-ASD: Let me continue that argument again. We're not arguing what you are proposing is bad or that it's not usable. It has a lot of utility and this notion of in the long run it will save money, we're not arguing. A program manager has to go in and ask for new money. That's money over and above what has been programmed and it makes it very difficult when that money starts to become sizeable. You are asking for money right now.

GIDLOW-S-KD: Well, one of the methods if I might suggest that to you is that it be made as a line item. Okay. A line item, a data line item for sustaining data and it can be a very inexpensive method for providing say a periodic review of change.

LOGUS-ASD: How expensive?

GIDLOW-S-KD: I don't deal with the dollars so I can't really tell you but I've seen some proposals.

I've seen some proposals for doing this type of thing. We have done it in the past on a voluntary basis, but I've seen some proposals that in are in terms of tens of thousands of dollars per year. Okay. To review those processes and for the application into the depot and hold periodic meetings with the depot people to view them for incorporation into the tech data.

UNKNOWN: I'd like to comment on Paul's comment. I think the military has to put some money aside, bootstrap money, if you will, for investment purposes. There are numerous projects, and I've been involved in several so I know, where a small investment makes a big return to the military in costs saved.

Now, I think a certain amount of money has to be set aside initially and eventually any money saved could go into that investment pool. It's just a suggestion. And that money then could be used again to invest in other cost-saving projects and I can see it building up rapidly.

McCLANNAN-NAVY: I would like to endorse this because,Paul ,if we don't pay for this as a line item initially, we're going to pay for it later on through the nose because we have to back engineer and we have to get it some other way and it's paid for eventually through DOD.

(Some crosstalk from audience with no mike.)

TOPIC: IN COUNTRY RELIABILITY DATA NOT AVAILABLE FOR FOREIGN MILITARY SALES

DISCUSSION: IN-DEPTH ANALYSES OF FIELD FAILURES ARE NECESSARY IN ORDER TO IDENTIFY AND CORRECT DESIGN AND/OR QUALITY ASSURANCE DEFICIENCIES SO THAT RELIABILITY OF INERTIAL SYSTEMS CAN BE IMPROVED. TO DATE, FMS CONTRACTS HAVE NOT INCLUDED A FORMAL RELIABILITY REPORTING SYSTEM AND THE RESULTING LACK OF DATA HAS HAMPERED EFFORTS TO ACHIEVE ACCEPTABLE RELIABILITY ON FMS PROGRAMS

LESSONS LEARNED: A FORMAL RELIABILITY REPORTING SYSTEM SHOULD BE ESTABLISHED IN-COUNTRY ON FUTURE FMS CONTRACTS.

BROWN-ASD: I'm not really very knowledgeable in this area. This was turned in by the engineer on the F-5 program and it seems that he couldn't be here today so I am filling in. Can you hear me okay?

Apparently the FMS programs to date have not had sufficient reliability data reporting to enable the contractor to enforce a reliability growth. And so the lessons learned from this is on future FMS programs efforts should be made to establish by contract an in-country reliability reporting system.

BRANN-LITTON: I'd like to comment on that since I've been over to Iran and Saudi to see our equipment there and it is true that the reporting is not very good. However, we don't have to go that far. It turns out that the data we get back from 66-1 and 3M which everybody knows is a system for maintenance manhour accounting and it's obviously not very good feedback for engineering.

Now when the 1975 Scientific Advisory Board for the Air Force looked at inertial equipment, one of the principal findings of the study was that the Air Force should immediately institute a good field reliability data system to get feedback to the contractors so he knows what's happening to his hardware and why so he can fix it when it breaks. It turned out that it didn't happen. And they specifically recommended that the F-15 program have such a system. And as you know, we still don't. And I think the problem is not only overseas, I think we have the same kind of problem here,quite frankly.

KENNEDY-AGMC: I have to second what Al is saying and I would also like to point out he just gave you one of the last items on the agenda which we weren't going to let him get to, but he just got to it. Are there any other questions. Is Jerry Blaine around? I have a message for him. Do we have any questions on this item?

BROWN-ASD: I might point out that AFLC is attempting to set up a data gathering system and the F-15 (?) is cooperating in that effort and so is (?)

Also at the time that the Scientific Advisory Board made the recommendation, we did look at the need for such a system and inasmuch as we did have a contractual

effort going on betwen Litton and MACAIR, we concluded at that time it was not right to develop such a system, so we did not do so. However, I point out again that the F-15 and the AFLC is attempting to satisfy that requirement at this time by satisfying a computerized reporting system and it could perhaps form the basis or forerunner of a reliability system. We're hopeful in this area, but there's still a lot of work to be done.

KENNEDY-AGMD: Would any of our foreign visitors like to comment on this item?

GILBERT: In this case you are going to support the foreign country at this level or are you suggesting that foreign users will obtain lists reliable performance ??

BROWN-ASD: Well, since I really didn't submit this one, I'll have to talk off the cuff. I would presume that the system would have to worked out as an arrangement prior to the letting of the contract, and that the avenues are infinite, I guess.

GILBERT-AUSTRALIAN AF: Are you saying you are asking us to pay for something that you want us to do to keep up with you or something. I'm not sure what you're getting at.

BROWN-ASD: No. What I am saying is that when we sign a contract for a foreign military sale, that we

must consider the problem of reliability growth and we must make arrangements contractually for tracking that growth. It hasn't been done in the past and I guess the suggestion is that in future contracts that we look to a method of doing that and the avenues are more or less infinite.

LOGUS-ASD: The reason for the comment is that the Air Force in many cases is the agent for the country involved and consequently when problems do crop up and you are faced with a situation of we have to do something to improve the reliability. The first question is is what is the reliability, where are the problems, how do they occur and without a data base of some sort, we're in no position to help. We're operating with little information and really at worst visceral arguments or at best back-of-the-envlope pieces of information and the reason for this, the fellow that works for me, he would like to have information,but to go back to the company and say, here's our problem, it looks like it's occurring here, these are the circumstances, it's a reasonable request. It falls back to the situation of being able to provide the kind of support that the host country would like to have.

MILLARD-BAC: Perhaps for once I could blow the UK's trumpet here and suggest that the Americans should take perhaps a leaf out of the British books and

sell a complete system and not just an aircraft. We sell back-up packages to go with our sales.

KENNEDY-AGMC: Would you go through that again. I think we didn't understand everything.

UNKNOWN: He said perhaps we should sell a system package rather than just an aircarft.

MILLARD-BAC: Technical back-up facilities, etc., etc. It's in our own interest as aircraft salesmen to know what's going on with the aircraft, the IM systems on the aircraft or avionics in general.

UNKNOWN: You are proposing to collect the data as well in the country?

MILLARD-BAC: Yes, indeed.

BRANN-LITTON: The aircraft companies overseas do support their customers with complete logistic support, maintenance and training and everything else, just as they do here. The point that is being made here is that this problem is not having good engineering technical data, field data about reliability. But we don't do that here either so it's not surprising that it wasn't translated over there. But there is a system -- I don't mean that facetiously, it's just a fact. It's not required for everything on an aircraft. It's needed for radar, it's needed for inertial systems, it's needed for special other kinds of equipment that are very high

value and there are unique cases where you want to identify something by serial number because by pulling out ten bad ones out of the field, you maybe can double the MTBF of a large program because of a box that bounces back and forth. So we rely on the depot to keep the records to do that. We should have information from the field as well. But the thing we are talking about here is reliability information so that you know what the mean time between failure is, what the differences between the squadrons are, which are the bad actors by boxes, and I submit that I don't think the British government keeps those kinds of records either. I don't know if they do.

MILLARD-BAC: This is probably true. It's not done on a goverment level,but certainly as an equipment supplier we keep track on such things as gyros, MTBF's, etc.

KENNEDY-AGMC: We have time for one more comment or question.

I think the next topic will be presented by Jim Greening of the Navy.

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TOPIC: SHIPPING AND HANDLING OF WRA/SRA

DISCUSSION: INERTIAL NAVIGATION SYSTEMS (INS) HAVE VERY DELICATE INSTRUMENTS WHEN THEY ARE IN A QUIESCENT STATE. UNFORTUNATELY, WITHOUT PROPER HANDLING, EQUIPMENT AND THE AWARENESS OF EACH PERSON THE EQUIPMENT COMES IN CONTACT WITH, MUCH DAMAGE CAN OCCUR. THE CONTAINERS AND PROPER HANDLING CAN MAKE THE DIFFERENCE OF A COMPLETE OVERHAUL OR A SIMPLE REPAIR OF A FAILED PART.

LESSONS LEARNED: (1) MOST MANUFACTURERS OF INERTIAL EQUIPMENT DEVELOP SHIPPING AND HANDLING DATA FOR GENERAL HANDLING OF THE INSTRUMENTS. MANY TIMES THIS DATA ISN'T SUFFICIENT FOR THE EXTREME HANDLING CONDITIONS OF SHIPPING TO AND FROM CARRIERS. IN EACH CASE DATA SHOULD BE EVALUATED FOR EFFECTIVENESS. (2) MANUFACTURERS' DATA IS NOT SPECIFIC MANY TIMES AND SOME MEANINGS ARE LOST IN THE TRANSLATION. FOR EXAMPLE, THE ASN-31 CONTAINERS FOR TEN YEARS WERE DIFFERENT AT EACH SITE. STANDARDIZATION OF CONTAINERS SHOULD BE MADE WHENEVER POSSIBLE. (3) THE USE OF COMMON INVENTORY ITEMS SHOULD BE USED WHENEVER POSSIBLE. THE DEVELOPMENT OF SPECIAL MATERIALS FOR PACKAGING OF ONE PARTICULAR ITEM BECOMES A MAJOR LOGISTICS PROBLEM AND SOMETIMES RESULTS IN SHIPPING WITH LITTLE OR NO PROTECTION AT ALL. (4) TRAINING OF PERSONNEL INVOLVED IN HANDLING DELICATE INSTRUMENTS IS A MUST TO REDUCE DAMAGE FROM HANDLING AND SHIPPING. (5) MUCH THOUGHT MUST GO INTO THE DESIGN OF CONTAINERS BECAUSE OF LIMITED SPACE ON CARRIERS. WE MUST GET MAXIMUM PROTECTION WITH MINIMUM SIZE.

GREENING-NAVY: Jim Greening again, and I am presenting this for Roger Logan.

This is something that General Rogers should receive some credit for since he mentioned it this morning is the problem of shipping and handling of WRA/SRA, which is the weapons replaceable assembly, and the problem we run into with the LN-2 ASN-31 is the fact that we

we were receiving platforms from the depot level at the intermediate and organizational level and they simply weren't working. And we began to get to the point of bad feelings between the three areas because we were putting platforms in aircraft and expending a lot of energy and it was turning out they weren't working and we would take the platform back to the depot level and they would show us the charts and the information showing us they worked perfectly.

So what we finally ended up doing was putting a recording accelerometer in some of the packages that we were shipping to various areas, shipping to carriers, we had some that we shipped to (?) and some that we were just shipping locally, and it turned out we were pulling as many as 40G's on some of these things by putting them on tractors, carrying them out to aircraft and running over cables and having airmen throw them down to ship's boats to take them out to the carriers and things like that. And this is where a great percentage of the problem lies. As it turns out, the basic reason this is up here is to make sure that personnel are trained in how to handle it, to make sure that the people that are doing the packaging are aware of the seriousness and the delicacy of what they're handling and make sure that each activity is in fact using a universal type of

packaging. We ran into a situation where the depot was using one type of packaging, the organizational level was using another type and the intermediate was using another type, so that it got so confusing that we finally had to come to the point that supply would refuse to accept a platform unless it was specifically packaged and that was the only way we were finally able to organize it. Any comments?

KENNEDY-AGMC: Jim, why don't you follow right in; you have the next one.

TOPIC: AN/ASN-31/36 (LITTON LN-2) SYSTEM IMPROVEMENT PROGRAM

DISCUSSION: TESTING PHILOSOPHY BECAME A MAJOR PROBLEM WITH THE REQUIREMENT FOR SUPPORT OF THE PLATFORM BOTH AT SEA AND ON SHORE. TO SIMPLIFY TESTING PROCEDURES AND COMPATABILITY PROBLEMS WITHIN THE TESTING AREA ONE PHILOSOPHY WAS CHOSEN. HOWEVER, THIS TESTING PHILOSOPHY DID NOT PROVE COMPATIBLE WITH AIRCRAFT OPERATIONAL REQUIREMENTS. AFTER A PERIOD OF YEARS, THIS PHILOSOPHY HAS CHANGED AND A SIGNIFICANT IMPROVEMENT IN SYSTEM PERFORMANCE AND RELIABILITY HAS RESULTED. SIGNIFICANT IMPROVEMENTS HAVE TAKEN PLACE WITH THE NEW TYPE OF BEARINGS IN THE GYROS AND BETTER CONSTRUCTED SHIPPING CONTAINERS.

LESSONS LEARNED: THE MOST SIGNIFICANT LESSON TO BE LEARNED FROM THE ASN-31/36 SYSTEM IS THAT COMMUNICATION IS VITAL TO THE SUCCESS OF ANY SYSTEM. EACH OF US THAT IS INVOLVED IN A PARTICULAR PHASE OF A SYSTEM SOMETIME BECOME SO INVOLVED IN OUR OWN PROBLEMS THAT WE LOSE SIGHT OF THE TOTAL PICTURE, WHICH IS TO BUY, SUPPORT, MAINTAIN, AND OPERATE A SYSTEM SO THAT IT PROVIDES ADEQUATE SUPPORT FOR THE MISSION IT WAS INTENDED TO DO.

GREENING-NAVY: Again, for Roger Logan. AN/ASN-31 system improvement program.

This was a situation whereby again one manufacturer made the item and another manufacturer made the test equipment and drew up the testing philosophy. And there was a great disagreement between what the manufacturer had wanted -- what the manufactuer of the item had wanted -- and what the manufacturer of the test equipment and the testing procedure wanted. And then there was also a disagreement between what the depot level was using as far as what they were using as test equipment and what the intermediate level was using, so what this is here for is to point out you must get the same philosophy no matter where you're operating. As long as everybody is operating on the same level, you're able to talk to each other, you're able to compare information to the point where you're not comparing apples and oranges and everybody's talking around each other. And there it again as it says, the most significant lesson to be learned from the ASN-31/36 system which,as old as it is has not died,and we're still stuck with it, the Navy portion of it, the A-6 (?) is stuck with it until 1985, is that communication is vital to the success and that's very true.

KENNEDY-AGMC: Do you have any comments or questions?

The next topic willbe by Mr. Brann from Litton

to give his third item.

TOPIC: CONTRACTUAL BASIS FOR RELIABILITY

DISCUSSION: ACCORDING TO THE REPORT OF THE USAF SCIENTIFIC ADVISORY BOARD GUIDANCE AND CONTROL PANEL, DATED MARCH 1975, DIFFERENCE IN RELIABILITY BETWEEN AIR FORCE AND COMMERCIAL INERTIAL NAVIGATION SYSTEMS RELATE TO DIFFERENCES IN PROCUREMENT AND MANAGEMENT PRACTICES.

SPECIFICALLY: (1) THE LACK OF CONTRACTUAL INCENTIVES TO DEVELOP INERTIAL SYSTEMS WITH HIGH INITIAL RELIABILITY, (2) THE LACK OF CONTRACTUAL INCENTIVES TO DEVELOP EFFECTIVE FIELD RELIABILITY IMPROVEMENT PROGRAMS, (3) THE LACK OF SUFFICIENT INCENTIVE TO MINIMIZE OVERALL MAINTENANCE COSTS.

LESSONS LEARNED: (1) A MAJOR REASON FOR THE HIGHER RELIABILITY OF COMMERCIAL INERTIAL NAVIGATION SYSTEMS, WHEN COMPARED WITH THOSE IN AIR FORCE INVENTORY, IS THE CONTRACTUAL INCENTIVE PROVIDED BY COMMERCIAL PROCUREMENT, (2) SIMILAR INCENTIVES SHOULD BE PROVIDED FOR MILITARY PROCUREMENT OF INERTIAL SYSTEMS.

BRANN-LITTON: This topic I think is really very simple. It simply says that if we really want reliability and maintainability -- there's no difference really in the two kind of requirements -- and if we really believe that they're to be considered in procurement circles as important as performance because of money for maintenance chewing up a great deal of budget, then it seems that all of the things associated with reliability should be in the contract. Now some of the things that I think are not always in the contract for reliability are such things as sufficient burn-in at the system level. We went into the F-15 program with only three cycles of burn-in; we

now do 50, but it was not initially a contract requirement to do 50 hours. SRAM program was 100 hours burn-in at the system level. The CAINS program is 100 hours. So two generations, or a generation of hardware later, it was reduced. Now there may be disagreement whether it should be 50 hours or 100 hours, but I'll tell you what the Litton philosophy is anyway. There should a minimum of 50 hours and an acceptance test that should be failure-free. Should be random vibration in the sell-out at the system level. Obviously there should be the full temperature cycling during the 50 hours of testing.

And if these things are truly required and agreed to by the community, then they ought to be part of the contract and not corrective actions later because they were overlooked at the beginning.

Obviously it's also true that incentives for the manufacturers are good things to do. The Scientific Advisory Board report felt that one of the major reasons for the commercial better experience in reliability was due to the difference in procurement practice, specifically the use of warranties and incentives. I think it's a factor; I don't think it's as large as they claim. I think most of the difference is environmental.

However, there certainly is a factor because of warranties and incentives and guaranteed maintenance is one

way, but I haven't seen very many incentives or warranties actually for MTBF guarantee. It's mostly negative incentives. Yes.

THOMAS-SASO: You know the airlines wouldn't have been able to achieve that had they not also been able to have the data collected that would give them the visibility of where the problems were after they went on contract. After they went on contract, as you say they did, then they went out and collected the necessary data so they would have the visibility to where the weak links were so they could fix them.

BRANN-LITTON: I'm not sure I understand the comment. Are you talking about the sytem level burn-in?

THOMAS-SASO: I'm talking about the whole system.. If you the contractor, go on contract to either the airlines or the Air Force to have a high reliability, you also have to have the necessary data of your failure mechanisms so you can know what you have to fix if you're going to improve your system. And the airlines that achieved that, those guys went right down to the nitty-gritty, they kept records. In fact I know of one company that kept all the failed parts and they still have them in their library today so they can go back and look at them.

BRANN-LITTON: I'd like to write the statement

of work. I'd love to see it in every contract, every RFQ we ever get that it would simply say that you will do 50 hours of burn-in, you'll report every failure, you will have physics of failure on every failure. Cause that's the last 50 hours, you already went through integration. So the last 50 hours every time you fail is is important. And since it's a failure-free loop and you gotta go back again it's expensive for the manufacturer. So we do it anyway. It should be reported, it should be (?) and it should come into the government. And then when you go out into the field there should be a system and that should be reported until you're through developing (?) all the way out there and at that time it should become organic. But up to then it should be reported by the manufacturer and all those records should be kept. This all ought to be in the contract as required things that are necessary for reliability and I'm not so sure I don't even think that the other end, for example receiving inspection at 100 percent testing parts and the things that need to be done at the front end shouldn't be required, because there's a fundamental difference between the way we do business and the way AGMC does business and there's no piece of paper that says they have to do it the same way we do. And so the hardware is being built differently

than it's repaired, with completely different sets of ground rules and philosophy, because it's not required. It's not contractually required. Any other questions?

(Questioner didn't use mike.)

BRANN-LITTON: 50 hours burn-in using the mission profile of the vehicle and that's exactly what we do. So if you have a fighter, for example, you'd have an hour and a half or two hour on cycle and you (?) at a low temperature, so typical profile say minus 55 to plus 71, you sit there and stabilize it right at minus 55 and then turn on and go up and stabilize at the high temperature, etc. So the profile follows exactly what it looks like in the aircraft. And the vibration level, too, I think should be performance level. So if it's 5.4 G's RMS type, that's what you do. Not endurance level. You're not trying to break hardware but you're trying to make sure that when it hits the aircraft it doesn't suddenly see something new for environment. Except centrifuge, cause I can't do that.

KENNEDY-AGMC: One more,please.

(Question unintelligible.)

KENNEDY-AGMC: What 781 version is it?

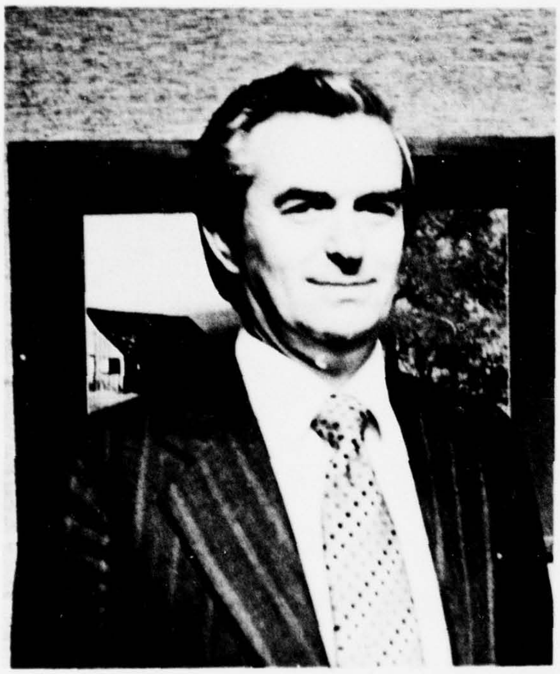
BRANN-LITTON: Well, the current version of 781 that's out now is B and when C comes out it will require additional type of testing. What I'm saying is the

requirement to do failure-free testing and the vibration, and C will have some of those things on, but it has to be imposed in the contract, the fact that it's available to be utilized doesn't mean it will be, because 781B is there now and most avionics contracts do not require the level of burn-in that they should, I don't think for inertial equipment. That's my opinion.

KENNEDY-AGMC: I think that's about all the time we have. We're going to break in a few minutes. I would like to point out that there are about six or seven items that we haven't covered. They will be published so you can read those. One of which is an update of the impingement spray process that we are using at AGMC which I think quite a few of you people are interested in. You can see this on the tour. They can set it up for you to give you a complete review of the impingement spray process.

The other thing I'd like to thank you people. I think was a spirited session. It's almost as good as a bearing session. Maybe a little later on we can get it more spirited. If you remember the session and the next year when the exchange comes out and asks you for items, submit items. We need more people to submit more topics for items. Thank you very much.

RELIABILITY AND MAINTENANCE TEST
LESSONS LEARNED WORKSHOP
CHAIRMEN



DAVE ANDERSON
FERRANTI, LTD.
SCOTLAND

LT COL GENE HYMAS
CIGTF
HOLLOMAN AFB NM

SESSION III

RELIABILITY & MAINTENANCE TEST

WEDNESDAY, 26 OCTOBER 1977

CO-CHAIRMEN: LT. COLONEL CARL E. HYMAS
CHIEF OPERATIONS OFFICE
CIGTF, HOLLOMAN AFB

DAVID ANDERSON
CHIEF ENGINEER, GRYO GROUP
INERTIAL SYSTEMS DIVISION
FERRANTI ELECTRIC, INC., SCOTLAND

BURKE HALL - DENISON UNIVERSITY

automatic test equipment for gyros, platforms and inertial nav systems. Dave, please.

ANDERSON-FERRANTI: I'm very pleased to be here as Scotland's sole representative, I think, but time is short so can we kick off on the first one, please. Mr. Al Brann, Litton Industries.

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DESIGN ANALYSIS FOR RELIABILITY/MAINTAINABILITY

A FORMAL PROGRAM TO ENSURE RELIABILITY IS DESIGNED INTO HARDWARE -

RELIABILITY PREDICTION AND APPORTIONMENT
COMPONENT RELIABILITY REQUIREMENTS AND DERATING
WORST CASE ANALYSIS
POWER STRESS TRANSIENT ANALYSIS
EXTERNAL VULNERABILITY ANALYSIS
DIGITAL TIMING ANALYSIS
NOISE ANALYSIS
STRESS ANALYSIS
TRANSIENT THERMAL ANALYSIS
FAILURE MODE, EFFECT AND CRITICALITY ANALYSIS, TOP DOWN
MAINTENANCE ANALYSIS
SAFETY ANALYSIS
PAST PROBLEMS CHECKOUT
BRASSBOARD PROOF TESTING

BRANN-LITTON: The subject is design analysis that should be done, in our opinion, at the front end of the design and what I'd like to do is show you -- this chart says should be designed in, I think we've all said that for many years, cost effectively, formally required and documented and also the changes must be documented and proved.

Now, the way that we approach it is we have a

set of engineering instructions within engineering at Litton and there are two requirements. The first requirement is for what I call opriori design analysis. That's design analysis that has to take place at the paper level, before you actually have hardware for testing. These analyses are released as part of the formal drawing structure and the requirement is that the analyses be released at the time of the design paper release reviewed by various organizations as a function of the type of analysis it is. Typically, it's reliability, maintainability and systems engineering when you are reviewing circuit work of other people from mechanical studies, etc., materials in process. It depends on what you're looking at. But the scenario is that the analysis is formally documented. It's not in engineering notebooks that you can't find two years later. It's done in a formal fashion. It's released, it's reviewed and changes get made then. The idea is if you do this analysis, you're going to have less failures later on when you actually have hardware tests and especially later on when you are in the field. The idea is to cut down on the number of design changes and so forth.

Now, this is a list of the analyses we actually do. If you look at them, you will see that some of them may be contractually required. For example, failure

modes and effect analysis may be imposed as a contractual requirement; it usually is these days. And derating is usually required also as part of a 217B reliability prediction. Most of the others are not. No

Now, we'll just touch on these briefly, because I know we don't want to spend individual time on each analysis. But if you look at them, the intent is to cover all of those things that are necessary to make sure that the system was designed correctly from a design point of view. So the reliability is apportioned at the module level to the designer, he's given a (?) so if you have a 1,000-hour system, you may have to have a 25,000-hour power supply,etc.

Each subassembly and each module is given a design bogey. So at design review an engineer has to stand up with his stress analysis sheets, which are formally released and filled out all to the same derating ground rules, etc., and he's added up all his failure rates and he says my bogey is 25,000 hours and I'm at 26 or 24 and that's the process that happens all before physical hardware is built.

So the second phase is when you have hardware now, you have brassboard hardware and you enter the lab phase of the program, you now do actual physical tests where you gomeasure on the hardware to verify your

design analysis was right. It's not possible, obviously, to do all things on paper. So now you go into the phase where you take the power supply up under max load at high temperature and you record it. You go find out what really happens under all the power conditions, input and output, cause there's lots of bad power cards out there. At least that's our experience.

So you do all of this all during development and if you do it and you document it and you do it right, the feeling is that when you go to production, you got several hundred changes that you've done on your own as a result of analysis that won't be ECO's when all the TO's and all the (?) and things are out there.

So what I guess I'd like comment on is do you think there is anything here we've missed from the point of view of analysis or other comments?

THOMAS-SASO: Yes, I think there's one area that we have found that we have good mechanical engineers and good electronics engineers, but we don't always go talk to the materials guys to see if we using good materials and often times we come up with super designs but we pick some materials that the materials guys just laugh at us why we ended up with those materials. So I think there's an area there. I'll just give you an

system improvement program.

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example; in the (?) Autonetics found there was a lubricant they shouldn't use. We just caught ourselves putting it in a ( ?) and we just turned around and said, oh, there's something we almost slipped upon. Somehow we've got to keep the materials people and the experts down in the microscopic level tied in with the guys in the larger level.

BRANN-LITTON: I mentioned material in processes before as being in the review. We generate materials and process specs for all the materials the same as component specs and they're treated the same way. We have an approve and depart list, you know, for components and a non-standard parts in the middle and we have an equivalent document and the same thing for process specs. So the thermal grease that goes under parts, the epoxies and all that. When they're on a formal drawing, like the making of a board, those things are called out on the actual drawing of the end item, subassembly, like a card. But if it's something that's used for solvents and cleaning and that kind of thing, I don't think those are normally submitted to a customer for review. I don't think they are used in the factory. I agree with you, those are very important things.

SERNAC-NEWARK: Have you ever taken an analysis--an after-the-fact analysis, in other words, I've done all

The next topic willbe by Mr. Brann from Litton



this and predicted all this and prorated all this and five years later I've got a guidance system that has this and my original prediction was X and my real world is Y and correlated my final results with what I predicted to see whether I got a program that does the job for me.

BRANN-LITTON: Yes, as a matter of fact, I have some very interesting data on that precise question.

First of all, let me make clear that we've only been doing what you see up here on the board for one year. We've always done design analysis and on specifc programs we've had contractual requirements for this kind of analysis for example in the SCHRM program that was contractually required. But it's only been a year that we've imposed this as a self-imposed across all programs independent of contract type requirement. So this is in effect now as of a year ago. Now, let me answer the specific question.

I went back and took every system that Litton has made. I started with the LN-12, I didn't go back before that. And I redid the predictions to today's ways that predictions are done because when they were done then they used RADC Notebook 217A and there's a whole history in progression of different ways of doing predictions.

the F-15 program with only three cycles of burn-in; we



I took 217B and I went back and I looked at the actual operating environment, what it did run at, what were the junction temperatures in the aircraft, how many pounds of cooling air did we have, etc. I did them all over. It was amazing. In the LN-12, suddenly the prediction was down around, I think the prediction was down to 200 and something hours now using today's techniques. So when we find out that the LN-12 gets about 100 hours or 90 hours, I'm not so surprised anymore. But the predictions that were done 10 or 12 years ago were much higher.

We also looked at recent programs like the F-15 and the CAINS and so forth. And part of that exercise led to our conclusion about the cycling as well. So we have done all of our hardware to the same base line and we can look at it and we think that a good deal of the reliability problems in the past were due to insufficient levels of tests, all the way from receiving inspection through the system level, which another which I won't bring up here because that's another topic that comes up later.

That was one thing and that's something we've changed in the last two years, very extensively.

The other reason was lack of adequate design analysis because if you do the design analysis at the front

warranties and incentives and guaranteed maintenance is one



end, you've got lots of options for trade-offs, but if you run into it later as a problem, now you don't have so many options because the chassis is there, it exists, it's designed and all of a sudden the changes become very expensive, so you don't have as many options available to you to fix the problem. So anything thermal should be done right at the front end when you have major packaging consideration. So those are some of the reasons we found when we went back and looked at the prediction -- of the prediction versus the actual.

And the last point was a lot of the older programs had very insufficient demonstration testing. First of all, they were done some of them under lab ambient conditions, which is ridiculous, no temperature cycling, and this is going way back now into some of the older programs and in other cases the corrective action proofing wasn't adequate. It was just statistically invalid, the relevancy, non-relevancy criteria that's been used over the run has just been improperly applied, statistically invalid.

And those are some of the reasons we found and where we try to change for what we found.

ANDERSON-FERRANTI: May we go on to the next presentation, please. Ray Clodfelter, AGMC.

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BRANN-LITTON: I'd like to write the statement



CONSIDERATION OF DIAGNOSTIC TESTING
REQUIREMENTS DURING DESIGN

DISCUSSION:

HISTORICALLY TEST CONFIGURATIONS HAVE BEEN AN "AFTERTHOUGHT" DURING DESIGN. EFFICIENT DIAGNOSIS HAS BEEN CONSTRAINED BY THE HARDWARE DESIGN RESULTING IN PROCEDURES WHICH ARE ULTIMATELY MUCH MORE COSTLY THAN THE ADDITION OF TEST POINT/ COMPONENTS.

LESSON LEARNED:

INSURE THAT ADEQUATE CONSIDERATION FOR EFFICIENT DIAGNOSTIC TESTING BE MADE DURING THE DESIGN PHASE. IN PARTICULAR, INSURE ADEQUATE TEST POINT/ SIGNAL CHANNELS: PROVIDE METHODS FOR EVALUATING THE PERFORMANCE OF THE INERTIAL INSTRUMENTS WITHOUT USING ANOTHER "SUSPECTED" INERTIAL INSTRUMENT(SUCH AS BUBLE LEVELS, SYNCHROS,. . . ETC.)

CLODFELTER-AGMC: If this item is to be considered a lesson learned, perhaps what we ought to consider is to call it a review lesson learned because some of us haven't learned all those lessons the first time.

We can see that we've come a long way in repackaging modules and those portions of our systems to get the functions as nearly as we can onto a single module. This has considerably improved the capability to diagnose.

At the same time, however, we have consolidated those modules into a more compact box where now we can get a computer and a platform and the electronic interface all into the same box and lo and behold we've got the same problem as we had before and the only thing we

can do -- there isn't a magic formula that says how we can do it. The case has to be that we do insure that there is an adequate consideration for designing an adequate number of test points. Any questions?

LAWRENCE-LITTON: We've been through this several times and it hasn't been mentioned here today, however some of the earlier sessions of this conference we talked about this. I think the reoccurring problem is what trade-off should we do on the number of test points. You can have infinite number of test points and get your 100 percent fault isolation. You have to have some type of trade-off. I realize that the questions brought up here are brought up by the using organizations. They say, you know, keep putting them in. From the other side of the field, engineering design point of view, they cost weight, size, money, reliability and things like this. The test points themselves are expensive. They aren't free. So we have to have a trade-off.

CLODFELTER-AGMC: I agree. And, of course, what we are saying is let's make sure the trade-off is done efficiently and come up with the best combination that we can.

LAWRENCE-LITTON: My real point is I think that

we should have something in numbers that we can work with. Some goal or perhaps the cost aspect or something like this that we use for a guide.

SERNAC-AGMC: I'd like to relate to that point back to the statement that I made earlier because someone came up to me and said that I said that I didn't believe in automatic test equipment. That's not what I meant in the earlier comment. A trade-off between test points is, I believe, is to break your testing down into sequential functions. If you have a gyro loop rather than you might check a whole loop out, does the platform stabilize. Can you break the functions down and determine whether or not -- automatically whether or not you have torquing signals, do you have a pick-off signal and the computer can automatically check these functions. So you don't really need to know whether or not you can have a test point to check those functions, just whether or not the system is tested, how you break your function down. So more functional testing, in an automatic sequence that you can stop and repeat functions is another way of getting around the test points.

HARRIS-NAVY: I believe the Navy has done something along this line with their compatability or automatic testing with AR8, 9 and 10. Are you familiar with those? Perhaps I would suggest that you look at

them.

CLODFELTER-AGMC: There might be some way we could get that information available to the attendees, I'm not sure. Or at least reference.

McHALE-NAVY: Chuck Shanning can give that to anybody who wants it. Contact John.

?: Do we have to pay for it?

McHALE-NAVY: No comment.

ANDERSON-FERRANTI: Any more questions? Pass on to the next one.

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TOPIC: RELIABILITY GROWTH TESTING

DISCUSSION: HARDWARE INTRODUCED INTO SERVICE USAGE USUALLY DOES NOT MEET ITS PREDICTED OR SPECIFIED RELIABILITY LEVELS. STUDIES HAVE SHOWN A LEVEL OF 10% OF PREDICTED VALUES AT INTRODUCTION INTO SERVICE. OVER THE LONG RANGE, THE REALIABILITY LEVEL USUALLY INCREASES AT A VERY GRADUAL PACE AND AT EXTREMELY HIGH COST LEVELS.

LESSONS LEARNED: THE RELIABILITY MATURITY OF HARDWARE CAN BE "GROWN" BY EXPOSURE TO REALISTIC TESTING LEVELS COUPLED WITH A RIGOROUS FAILURE ANALYSIS AND CORRECTIVE ACTION PROGRAM. THIS OBVIOUSLY IS MOST COST EFFECTIVE DURING THE DEVELOPMENT PHASE.

BRANN-LITTON: (Did not record) . . . testing in a very large way in new NAVAIR procurement and our point here is that the development phase of the program is the time to do reliability growth testing, not the operational field environment, obviously. And it requires

quite a bit of testing. You have to have a reasonable amount of hardware under test. Basically, you need at least one system for maintainability for inserting all those faults, verify tech (?) and all the things that have to happen before you go to a maintainability demo. And you need to have one hardware for (?) growth testing, that's dedicated, where you can go in and do all this parametric variation we were talking about at the system level. Then you need a system for systems integration, or for systems engineering, rather. Now these are usually not provided for in contracts, and they should be. The other point is that the tests should be very carefully monitored and the failure reporting should be very rigorous with detailed physics of failure by M&T, component engineering, wherever the problem fits. And it should be mapped out as an integrated thing at the front end of the program, so it's very clear what the milestones are. There are usually growths associated with reliability growth testing, factors, the slope of the curve that you're expected to follow. And if that's all done right and it's funded and it's contracted for, it's a very valuable tool for coming out of development with a piece of hardware with a known reliability.

In the absence of reliability growth testing,

then we have what's called field maturation and we all know what that is. And the only way to avoid that is to do it during development and have enough time, enough money to plan it and put it in the contract. It can be grown during that point in time by taking corrective action. And it's also the time when you have the best talent of the people who designed it available to look at it. It takes a lot longer to find it later, when those people are off working on different programs, which is usually what happens. Any questions?

RIPPLE-DELCO: I'll make a comment. I don't think he was here last year, but that's McHale's rule of thumb, isn't it, the 10 percent rule we talked about that last year. In the contracts today -- you're talking about the past. The contracts today are going to take care of that. No longer can you build a piece of gear that doesn't work and then be paid to improve it. The contracts today are going to take care of that. The Air Force is well aware of that.

BRANN-LITTON: I'm not sure if you really mean that. Are you saying that every program is going to have a developmental program with hardware that's designated for reliability growth testing?

RIPPLE-DELCO: I'm saying that today, in today's world, the government will procure against, at least it's my

opinion, they'll continue now to procure against the reliability improvement warranty so that the manufacturer won't be able to come out with a 10 percent of his predicted value. He'll bid, guarantee it , and pay for it if it doesn't perform at that level, and any improvements made to the hardware will be at his expense, not at the government's expense.

BRANN-LITTON: That may be true. I don't think IRW is going to be used quite that widespread. I think in selected areas we've seen it as a guaranteed maintenance fix price overhaul and repair type contract, but I don't see many RFQs coming out for RIW MTBF guarantee type across all avionics or all inertial, in particular. I think it will be selectively applied, yes. And also target logistic support cost type of thing and all of those are being used selectively on different programs. You're talking about the penalty if you don't design and build reliable hardware, there's a penalty later because you have RIW. That doesn't help anybody, that just says the guy did a bad job and he gets punished. Before you even get there, what I was talking about, is having the kind of development program so the contractor makes it and he's successful. And the government's successful and they get good reliabile hardware. Being penalized later, that's terrific, that's good, but that still doesn't solve the problem.

The problem is to have the right kind of developmental program that's planned with hardware.

THOMAS-SAMSO: I like what you say and I think we ought to even go a further step and that's when we field the first squadron of an aircraft, we should really have everybody out there with their notepads to find out what's going wrong and fix them before we get many, many squadrons and try to fix it. We should do what you're saying for the first (?) and for the second (?) we ought to have one squadron really scrubbed down, everything that happens and then really fix it, and then we'll have a mature system. I agree.

BRANN-LITTON: Isn't target logistic support cost type of stuff supposed to do that, go out for quite a period of time and you record all of the manhours and all of the costs associated and so forth, at the whole weapon system level. I think that's the plan to do that.

ANDERSON-FERRANTI: Okay, I think we ought to get on into the next one.

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TOPIC: INTEGRATED TEST PROGRAM AS A FUNCTION OF DESIGN

DISCUSSION: THE ADVANTAGES OF AN INTEGRATED REST PROGRAM ARE OBVIOUS:

MORE EFFICIENT USE OF FACILITIES AND PERSONNEL
ESTABLISHMENT OF REALISTIC SCHEDULES AND PRIORITIES
CONSISTENCY OF TEST PROCEDURES AND TEST REPORTS
MINIMIZATION OF UNNEEDED REDUNDANCY IN TESTING
CONDUCT OF TEST READINESS AND TEST COMPLETION REVIEWS

THE PROBLEM IN THE PAST HAS BEEN THAT THE INTEGRATED TEST PROGRAM WAS NOT INCLUDED AS A PORTION OF THE DESIGN PROCESS.

LESSONS LEARNED: ESTABLISH AN INTEGRATED TEST PROGRAM AT THE BEGINNING OF THE DESIGN PHASE AND DEVELOP ALONG WITH THE OVERALL DESIGN. APPLY ADEQUATE RESOURCES TO THIS EFFORT EARLY.

AVENGER-LITTON: We're talking about an integrated test program here which sounds great and I'm sure everybody is all for it. We would all agree, I'm sure, on the advantages and that is you can read them there. Efficient uses of facilities and personnel scheduling, test procedures, test reports, minimization of redundancy where it's not needed, conduct of your test readiness and test completion reviews.

What we have done at Litton is we have set up this program, this integrated test program under the direction of an integrated test program manager and it is supervised by test control board, which handles all

of these functions. This thing is, on the F-18 program, in place right now and the problem in the past has been some people might have done this. They usually don't get started soon enough. One of your design parameters should be how will I test to verify that I have met my requirements. This should be part of the design, one of the trade-offs that you have to consider. Since we have done this, we have made, we have gained a lot of valuable experience. We have learned a lot in doing this in the early phases. We have seen things that you normally don't see until you get further along in the program. Such things as test equipment allocation. You find that by doing a little smart planning in the early stages of your program you can sometimes eliminate the requirement for some of your equipment, instead of waiting until you get boxed in by the pressures of schedules, that sort of thing, and find that you don't have any options left.

The lesson that we've learned is that you should establish an integrated test program at the very beginning of the design phase and use that along with all your other engineering tools such as your analysis we just talked about and it is very cost effective. Any comments or questions?

WALKER-CIGTF: Could you give us any examples of where you recently have used an integrated program that has worked for you?

AVENGER-LITTON: Yes, we are using it right now on the F-18 program for the Navy and one of the things that has happened to us very early, like I said, was we discovered that we could use some little more efficiency in the allocation of test stations by planning ahead in the very beginning and reordering the sequence of some of the testing which really there was no technical reason why one test came before another or that they had to be run together kind of thing. We found out that we could get by with fewer test stations. That's one of the things that's happened.

BRANN-LITTON: I'd like to make a comment about that. The integrated test plan for F-18, the document is about two inches thick. The kind of things that you find in that plan, when you write it at the front end, you have to identify all your test equipment, all your fixturing, all your cabling. Then you've got all the procedures that need to be written in advance at the front end of the program. It all has to be in place before you start the test. And we were quite surprised to find out that the document, the test plan, would end

up being such a large document. But when you get the people together that do the test, the people that are actually running it and understand the hardware and all the things, and you get them in a room, call them a test board, and you've got all the functions represented, it's amazing the number of things that actually go into a test plan.

Now, it's always been done. People conduct tests when they get through and many, many people have successful integrated test programs. This is not novel to Litton. We're coming on a little late with it because it's normally been applied when you have a large multi-block, large weapon system. But we are finding it useful at the individual system level because the kinds of testing that are required are so sophisticated and there's so much testing going on at the same time, that if you don't have it all integrated, for example, all the data from all the tests has to go through one organization. You can't have the failure data in different parts of the plant, or you won't know where you are. All that has to be centralized and controlled as well as the allocation of people and everything. So to answer your question, the first program we are doing this in a big way is F-18 and we have submitted to McDonald-Douglas an integrated test program plan with all of the elements

of the plan in it and now we're starting into the phase now where we're started into the plan.

ANDERSON-FERRANTI: Any more questions? Okay, on to the next one. Buddy Bleichroth.

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<u>TOPIC:</u> ASN-90 IMU CERT PROGRAM

<u>DISCUSSION:</u> (1) JOINT AGMC AND AFFDL EFFORT
(2) DETERMINE CERT APPLICATION FOR:
(a) DEPOT REPAIR
(b) FAILURE MODE OF ANS-90 IMU

<u>LESSONS LEARNED:</u> (1) CERT DETECTS FAILURE MODES
(2) ENSURE REALISTIC PROFILES
(3) PREDICTS FAILURE MODES FOR OPERATING EXTREMES
(4) ENSURE TESTS DUPLICATE AIRCRAFT OPERATION (NAV MODE)

BLEICHROTH-AGMC: Bud Bleichrtoh. I am from AGMC Inertial Engineering. This presentation addresses the use of combined environmental reliability testing (CERT) on the ASN-90 inertial measurement unit (IMU).

The Air Force Flight Dynamics Lab and AGMC conducted joint CERT programs on the ASN-90 IMU, used on the A-70 NAV aircraft. There were two objectives in the programs.

The first was to evaluate the use of CERT for failure diagnostics in the depot repair of inertial systems.

The second was to determine the value of CERT

in estimating the reliability of new inertial systems.

The first program consisted of environmentally testing ten IMU's that had failed in the field and passed all depot level tests. Seven of the ten failed performance specifications. We had excessive peak velocity errors and excessive rate of change in vertical velocity. Three of the seven also had hard failures of electronics that were dectected only when subjected to the environmental testing. Three IMU's passed all the tests. All the failures were induced by changes in the temperature of the flow air. There's a (?) on the A-7 aircraft which produces cooling air to the A-7 fan, and the A-7 environmental control is not very good, really. What it does, it supplies cooling air and the only control on it is if it gets to minus 65 it cuts off the cooling.

Since this was the only failure mode exciter that there was, it was easy to duplicate the test at the depot just by supplying variations in the cooling air supplied to the IMU.

The second program, CERT's ability to estimate reliability consisted of three IMU's that are to receive approximately 800 hours total test time. This test is still in progress. As a matter of fact, it will be completed

this week. The failures detected in this program were also attributed to the flow air.

Lessons learned. The first lesson learned is that there are failure modes that cannot be detected by static testing, which everybody already knew that. But they readily show up in real or simulated environments.

Secondly, realistic environmental profiles must be chosen for CERT. The profiles chosen for these two programs were for tropicand arctic operations, and were extremely hard.

One of the IMU's that failed CERT in the tropic environment was sent to Davis (?) Air Force Base and has flown many successful missions, as a matter of fact, over 30. I was just talking to Ted Grover, which is attending the meeting here, and he said it's in one of the aircrafts that's been picked for competition in the bombing derby. So it's doing real good even though it failed in that harsh environment because normally the aircraft is not used in that kind of environment. Davis (?) was the warmest base we could pick around, although at this time of the year it's not too bad.

Another plus for CERT is it's ability to duplicate operating conditions for extreme environments. This will yield valuable data on failure modes and failure rates

if the aircraft is to be used in the areas of extreme environmental conditions, although you may not want to spec out a system to operate in these conditions all the time, you can predict how it's going to act if it has to operate in those kind of conditions.

Several other things that were evidenced by these programs are: the first is to ensure the test performed duplicates aircraft modes of operation, specifically navigation tests. Normally in tests on inertial measurement units and systems, a lot of times they are tested like a black box and they only look at gryo repeatability and so forth. In a CERT type program, I think they should test it with the complete system, maybe not the whole system in the CERT or combined environmental chamber, but maybe one portion at a time or so. But it should be operated exactly like it's going to be in the aircraft. So you can look at how it performs.

Naturally we always want to record the maximum amount of data possible, acceleration errors, velocity errors, position errors and heading errors.

Second, the environment system the electronics is exposed to should be as benign as possible. This may be accomplished by providing an aircraft environmental system with better controls or designing inertial systems

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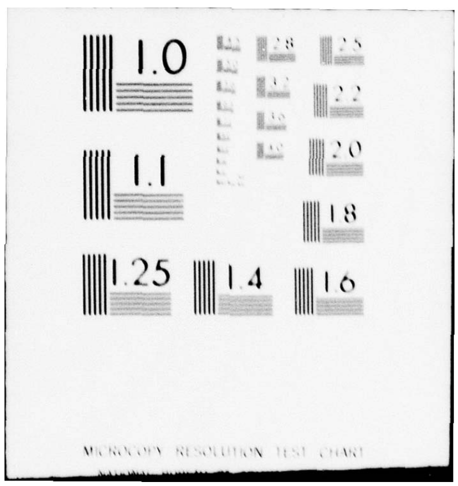
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MICROCOPY RESOLUTION TEST CHART

with the electronics environment controlled more like the inertial instruments. The newer systems are coming with better environments for the electronics. They don't have air flowing directly across the electronic components, conduction type cooling. So this should be a lot better.

In conclusion, it looks as if CERT is a viable, relatively low cost method of duplicating failure modes which in the past could only be achieved by expensive flight tests. Thus the acronym CERT suggests that bad taste and high cost of procuring environmentally deficient systems can be reduced.

HARRISON-HAVY: Buddy, have you given any thought as to what type of simulated flight dynamics that we could put into our testing at the field level?

BLEICHROTH-AGMC: You have the best thing in the world there. You're flying up in the aircraft every day at the field level. So you really don't need anything at that level. All you have to do is to be able to get all the information you can out of the pilots. Or in new systems, have a computer that records the data for you. A combined environmental chamber for every field site is strictly out.

ZIGONI-HOLLOMAN: One of the things you pointed out which is the danger of CERT is the use of the proper operational profile. As you stated, using the particular

system in a, I believe you said, tropical area, it failed. So this is an area -- what have you done to compensate for the over-testing as apparently you've done? The question may be did this go beyond the spec requirement of the aircraft.

BLEICHROTH-AGMC: Well, I don't know if that goes beyond the spec requirements. I really don't know what the requirements were on the A-7 aircraft, but I imagine most aircrafts are specced out to operate in both tropical and arctic environments, even though only a small percentage of their time may be in those environments.

NIEWOOD-SINGER: The system is specced to operate in both the arctic and the tropic environment. I think more work has to be done in the area of CERT; I think that's a good start. I think you do have to arrive at a more realistic profile. No plane that I know of flies from the arctic to the tropic in an hour and a half or 25 minutes, which is what we see in some of these MIL-STD-781 environment. So I think environmental testing is very useful, but I think also I would agree with Pete that it has to be more realistic and I would look to the Air Force labs that are presently concerned with CERT to come up with a more realistic test profile for this purpose.

BLIECHROTH-AGMC: Well, each profile is separate. We do a tropic mission and next you may fly an arctic mission. But no one mission went from an environment of tropic to arctic or arctic to tropic. The only thing is when you are in the tropics and you have a high temperature on the ground and you're blowing air through the system, it's 100°. And you go on a bombing mission and fly up at a high altitude and the aircraft generates cooling air that cools it down to minus 50°, that's a temperature differential of 150° in that flight. Then we you start bombing, the temperature goes up. The faster you fly the warmer the air comes in to the aircraft. So it's pretty rigid, but supposedly the A-7 aircraft is instrument and these are realistic profiles for that type of environment.

NIEWOOD-SINGER: What is the profile that you used? What was the temperature ranges?

BLEICHROTH-AGMC: Well, on the tropic, N-2 mission, which was a short mission, was a navigation of 1.9 hours. The temperature went from plus 100°, this is the cooling air that goes through the IMU's, right to the fan, 100 ° F and it went to minus 50° at a rate of about 20 degrees per minute. And it flew along at some levels for a half an hour and gradually

up to about 70° F. But that transition from plus 100 to minus 50 is practically where all of them failed. And it was mostly all the (?)

(?): By the way, did those failures that you found correlate with the reported complaint?

BLEICHROTH-AGMC: Not in all cases.

THOMAS-SANSO: Bud, this looks great for the electronics, but what about the case of inertial instruments where you had G sensitive terms, how do you compensate for sustained G forces you might see in the airplane which might be kind of hard to do on the surface.

BLEICHROTH-AGMC: That's hard to do for the inertial instruments. There's no way of doing it. The only thing you have is the vibration and that doesn't help you with sustained G forces. It's kind of hard to put a centrifuge inside an environmental chamber.

GIDLOW-SINGER: In the electronic failures that you experienced in the pre-cards in particular, were these failures other than those that had normally been found under the tech data prescribed for the card test?

BLEICHROTH-AGMC: You mean if the card was pulled and --

GIDLOW-SINGER: If it was pulled and you tested it per the prescribed test, would you have detected

that failure?

BLIECHROTH-AGMC: Okay, the way the tech data is written out and you may or may not have seen it, because you're not exactly looking at it during a transition of temperature now. You're looking at it at two different given temperatures and looking for a delta between that. Most of the problem stems during the transition.

GIDLOW-SINGER: But would it also have occurred during the normal test mode? Did anybody try to correlate that?

BLEICHROTH-AGMC: Well, we're working with those problems.

ANDERSON-FERRANTI: Can I pass over to Gene Hymas?

HYMAS-CIGTF: I do think we have some more discussion on CERT, I think in later papers coming up. One of the lessons I've learned already out of this experience is that Mr. Brann from Litton is the major contributor to this workshop, so we'll hear from him and, Al, I suggest on this one you take the next two together.

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TOPIC: LOWER LEVEL PRODUCTION TEST PROGRAM

DISCUSSION: THE PURPOSE OF A LOWER LEVEL (COMPONENTS, MODULES, CHASSIS HARNESS) TEST PROGRAM IS TO FORCE FAILURES TO OCCUR AT THE LOWEST LEVEL OF ASSEMBLY. THE TEST FLOW IDEALLY FOLLOWS A FUNNEL WITH THE MOST DIFFICULT SCREENING REQUIREMENTS AT THE COMPONENT LEVEL.

AT LITTON, THE LOWER LEVEL TEST PROGRAM INCLUDES:

EXTENSIVE COMPONENT LEVEL TEST INCLUDING: 100% ELECTRICAL TEST AT TEMPERATURE EXTREMES: HERMETICITY: SOLDERABILITY AND DESTRUCTIVE PHYSICAL ANALYSIS (DPA)

AUTOMATED MODULE LEVEL TESTS AT -55°C, +25°C, +90°C

AUTOMATED CHASSIS HARNESS CONTINUITY AND SHORT CIRCUIT TESTS

LESSONS LEARNED: 1. A THOROUGH COMPONENT RECEIVING INSPECTION TEST PROGRAM IMPROVES THE QUALITY OF INCOMING LOTS AND SIGNIFICANTLY REDUCES FIRST TEST MODULE FAILURES.

2. A LOWER LEVEL TEST PROGRAM IS COST EFFECTIVE BY ITS REDUCTION OF TEST FAILURES AND REPAIRS AT SYSTEM LEVEL.

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TOPIC: SYSTEM PRODUCTION TEST PROGRAM

DISCUSSION: RELIABILITY CANNOT BE TESTED INTO HARDWARE, BUT TESTING IS REQUIRED TO VERIFY PERFORMANCE REQUIREMENTS AND TO SCREEN OUT INFANT MORTALITY DUE TO DEFECTIVE PARTS AND FABRICATION ERRORS.

AT LITTON, THE SYSTEM PRODUCTION TEST PROGRAM INCLUDES:

SYSTEM LEVEL BURN-IN UTILIZING MIL-STD-781 TYPE TEMPERATURE, ON/OFF AND SINE VIBRATION CYCLING

RANDOM VIBRATION IN X AND Y (AND SOMETIMES Z) AXES

FAILURE FREE RELIABILITY VERIFICATION AND ACCEPTANCE TESTS.

LESSONS LEARNED: INTRODUCTION OF SYSTEM LEVEL BURN-IN, RANDOM VIBRATION AND FAILURE-FREE RELIABILITY VERIFICATION TESTS EFFECTIVELY SCREENS OUT INFANT MORTALITY FAILURES AND IMPROVES CUSTOMER ON-RECEIPT TESTING AND FIELD PERFORMANCE.

AVANGER-LITTON: It's a little difficult being a stand-in for Al Brann. I'd like to talk about establishing a comprehensive production test facility.

And basically what we've done at Litton is we've taken a look at the complete test requirements for the production of a given inertial nav system and gone back to the outside world and to us that is to our suppliers of the product and we developed a comprehensive test program designed to test the electronic and mechanical components at the most rigorous environment that they are specced to meet. We scale this down by a (?) technique and we get right down to the requirements of the system.

The first phase of this at receiving and inspection is the establishment of a 100 percent test for the components. This is done with integrated circuits. Every integrated circuit that comes in the house is tested for all of its electrical parameters at three temperatures, the maximum requirements of MIL-STD-883. We also do comprehensive lot sampling for solderability, hermaticity. We do PDA, which is physical destructive analysis. We

take a small sample of the given lot and do a complete internal examination of the integrity of the parts internal. The analysis of that data determine whether the lot is accepted or not.

The next phase, moving out into the factory, as we go into the module world. Here we test all the modules again at three temperatures. It is slightly degraded temperatures, but it appears the temperatures for the module is still greater than what the system will see. Typically we go from -55 to +90. Every module goes through these three temperature tests before it is integrated into the system.

The next phase, we go on into the system and the system requirements are usually specified by MIL-STD-781 or some other customer requirement. They're typically -40 to +71. So you can see that we have a so-called funnel where the system requirements for temperatures of electrical is -40 to +71, for modules is -55 to +90, components, for example, are -55 to +125. That's the basic funnel concept that we use throughout the factory.

Now to implement this, we've gone into selectric automatic test equipment, which is a very thorough study of test equipment and analyzed what we need for our particular requirements. And throughout the factory, we have special design equipment to do that. Not one large tester, but a series of small testers designed specifically

for the job that they have to do.

I guess to make this as short as possible, the lessons learned are a lot when you establish a program like this. First of all, the incoming quality of the components have been significantly improved because when you go out into the supplier world, there's a saying by various suppliers that those who test get the best. And believe me, when you establish a 100% testing requirement at the receiving inspection level and you start looking at what you had been receiving from your suppliers, then after the normal three to six months feedback, you'll watch that incoming quality improve.

The next step that we learned is once you take those good components and you put them on your board, then you assemble them, then at the first test, what we call the in-cost will start to drop because your yield at the first test will start going up. Now that is a measure of performance of the incoming quality of the parts and how they're installed. So if the incoming yield increases significantly, it says that your component tested correctly coming in from your suppliers.

The next step, is you go on out into the system level. Now, we've established, and firmly believe in the production reliability test concept and we've established requirements for CRT testing on every production system.

In fact, the minimum requirements, whether specified or not, is 50 hours of burn-in or 15 cycles.

Now in the system level in our production reliability tests, we had every system get the minimum of 15 cycles ofCRT testing. It also gets random vibration testing and there's a particular reason -- one of the reasons we believe in random vibration testing is that when you use MIL-STD-781, which has a sine (?) 2.1 G vibration requirement in it, you have problems out in the field that can go undetected. We adopted random vibration and it turned out to be a very powerful tool for eliminating latent fabrication problems that could get out into the field.

So in summary from the production reliability tests, from the system level and from the components, we believe thoroughly in that particular philosophy of CRT testing, starting with the components through the modules,a significant number of CRT cycles, 15 cycles, 50 hours of burn-in, plus a failure-free ATT and that is our basic lesson we've learned.

SERNAC-AGMC: When we get that system in and we repair it, we go back and buy all the components that that guy couldn't sell to you the first time and put them in the unit. My basic question then is when you take that equipment or the requirement document and

sell them to the Air Force, I'll speak to ASD or whoever buys it, you know, if we don't buy those component test requirements and specifications because currently AGMC does not take incoming IC's, transistors and put them through a program like this, we are going to buy the components that you rejected.

AVANGER-LITTON: In some cases, that's correct.

McCLANNAN-NAVY: What the Air Force doesn't get, the Navy gets. We're the third generation.

BRANN-LITTON: I want to make a point. You know you do buy the components specs as part of non-standard part submittal. I mean, I don't know of any program where there's not a non-standard parts submittal, but you've got a bigger problem than that. These are military standard parts mostly we're talking about. These are G&TXD semiconductors, MIL-STD-883 BIC. So there's no non-standard part. Those are military standard parts and when we started out they were running about, for electrical, about 6%. We're down to a 1% electrical failure. That may not worry you, but you think about a system with 3,00 integrated circuits, 1% doesn't meet the electrical parameters. That's the problem. When you look at hermeticity and solderability, you get up to numbers like 12% and 15% rejection for not meeting the specs. They leak, the integrated circuits will leak.

So, the point is that even if you had the spec, the fact is that the military standard devices that you would be buying in that are not non-standard also need this kind of testing. So as soon as the program is transitioned to you and the parts no longer come through our receiving inspection, you have that problem. I don't know how to solve that.

THOMAS-SANSO: I'll tell you where the problem is. We get the good equipment (?) then the procurement regs say that we will buy the most cost effective part, the part that's the cheapest that we can get ahold of. Now, there's some parts where they specify you'll have it, but usually after a couple years somebody will come across some engineer's desk and they'll relay it to competition-type buying and then the very cheapest parts, even the ones that couldn't even qualify to sell the ones these guys won't accept will come in and sell those parts to you and that's where it happens. It's in the procurement regs of the United States Air Force, the way we go about buying material from the cheapest bidder.

McHALE-NAVY: There's a psychological thing that Litton is not mentioning here, but I will. If they buy, let's say, a unit of 100 lots of let's say resistors, they'll negotiate and let's say they'll accept

one failure out of 100. They test 100 of them and three fail. They'll turn all 100 back to the contractor and they won't tell their vendor which three were bad. That's the psychological thing. Their vendors now have 100 bad ones and they know there's three bad ones in the lot, but they don't know which ones. Now, there is what is really the psychological thing, working on the hundred.

(?): That is correct, that's a good lever. The vending community learns very quickly.

(?) -GERMANY: I go along with you that it is absolutely necessary to screen components even when they are specified and qualified to MIL specifications, the MIL system for components is some 20 years old now, but I don't go along with you as far as microcircuits are concerned. MIL-M38510 is a very new specification. I believe it's the only one which is sufficient for military application. It's very, very severe and I don't know about your experience with those parts, qualified parts, according to 38510 in the (?) for a greater amount for a year or a year and a half only. So I don't know whether you actually have too much experience with this specification and I think it is very much better than all the rest of them.

AVANGER-LITTON: I concur with that. 38510 is a step in the right direction, particularly over what's

called the non-standard parts. But I think if you'll look at actual test results on 38510 parts and we've been testing them, every one of them that comes into our factory for about two and a half years, since the 38510 was released and we're using them on a large number of programs, that we found that the rejection rate incoming to us is in the order of 2.5% and we've gone through a lot of dialogue with a lot of suppliers and we've talked to (?) and the people back at (?) and right now that quality level from our supplier is down in the order of .5% for 38510 level parts. Now, .5% is a very significant improvement over 2.5, but it's still a step better than the non-standard parts which were running on the order of 1%. So you have to look at the trade-offs as to whether .5 percent would give you a problem from a production point of view. Maybe you can live with the rework cost at the system to find .5 percent of the parts in your factory. But based on our volume, .5% is a significant contributor to the in-cost, therefore we prefer to screen them at the front end and put the burden on the supplier.

(?) GERMANY: I believe you are trying to outwit statistics. You will never get below a certain margin of rejection because everything you're doing,

even when you are doing it on a 100% basis, is a statistical thing and you will always accept bad lots and reject good ones.

VERNON-MACAIR: I don't know, Mel, but everybody here may not know the failure-free burn-in was not originally in the base line F-15 requirement and the F-15 INS was the first system to go to this ACP and I think McDonalds is well pleased with the failure-free burn-in. Other systems have changed. We were afraid of a bottleneck in production, a lot of concern, but we found add-in failures sooner than we ever would have in the samples, MIL-STD-781 test. So it should be considered, I think, for future programs as a contract requirement.

HYMAS-CIGTF: Let's press on to the next topic. Unless somebody's really dying to jump up here. We have just a little change in philosophy here. I'd like for Mr. Robert Silva to present his topic. He's vrom Vector.

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TOPIC: AVIONICS RELIABILITY

DISCUSSION: 87% OF FIELD FAILURES ATTRIBUTED TO PRODUCTION PROCESSES

LESSONS LEARNED: USE SAME TECHNIQUE FOR SYSTEM THAT IS USED FOR COMPONENTS: PRODUCE - TEST TO FAILURE - ANALYZE - MODIFY PROCESS - REPRODUCE - RETEST - ANALYZE

USE CERT

AVIONICS RELIABILITY CANNOT BE ADEQUATELY IMPROVED BY CHANGES IN WHAT IS DONE IN THE LAB, BUT ONLY BY CHANGES IN WHAT IS DONE ON THE PRODUCTION LINE

MUST HAVE A NEW PHILOSOPHY IN AVIONICS TESTING

SILVA-VECTOR: I'm Bob Silva from Vector. We're located in Dayton. We're obviously not a very large engineering organization, but we do exist and the topic written down here, avionics reliability, was chosen to be very narrow so we'd have something very specific to discuss here this afternoon.

Most of the things that have been talked about today, we have published in a document that appears in the NACON proceedings this year. Some of the stuff that we will show you in a minute came out of that publication.

Our philosophy here says production line is the real culprit in reliability. I think you probably recognize from discussions up to now that reliability is probably a procurement problem more than anything else. How you buy determines whether you get a reliable system or not.

We were asked last fall by AFLC headquarters to take a look at field failure problems in foreign military sales aircraft. We looked at a number of different countries, a number of different aircraft systems to try

find out why there was such a very high failure rate in the avionic systems in these airplanes. AFLC was unhappy with it and they were apparently made unhappy by customers. They were experiencing things that they didn't think they had actually bought.

So we began to take a look at the problem. We gathered data from a number of different countries, as I said, a number of weapon systems and we found something rather peculiar, at least to us. Now we have a background in production processing research. We've been associated for the last ten years in component proudction processing. We're looking at electronic components and alloys and a number of other things, looking particularly at the processing problem. How you get reliable components.

Well, when we evaluated all this field data, we saw the same pattern existing. We were looking at avionic equipment field failures which told us that the problem was in the production line. We were looking at production processing problems again. We couldn't understand quite why this would occur; why we were seeing this kind of thing here, so we began to backtrack into history.

We went back about 20 years and we found that, you know, you see the inertial navigation system up there, designed for what -- specified 750 hours and its flight

MTBF was about 57, 10 percent. Those of you that were here last year remember John Ruth saying I have a rule of thumb. When a contractor says I'm going to give you a 750-hour system, my thumb says 75 is what I'm going to see off the production line. Well, sometimes it's even worse than 75. But that rule of thumb, John Ruth's rule is actually a historical fact and you can track it back years and years and years.

So we decided to look at other systems beyond the FMS system. We looked at Air Force systems and found the same thing. They all look like production processing problems to us, because that's what we were familiar with.

Well, from this information we developed the philosophy of approach to avionics manufacturing. When you get the first article off the production line and this is a historical fact, there you are over at the far right-hand side, see the number 20 -- I've been very generous, I said 20 percent -- as a matter of fact, it's only about 10, 10 percent of design.

That MTBF growth portion there is what Al Brann was talking about a little while ago. It can in fact be grown. There are some systems where MTBF has been grown. Taking production systems and putting them through a test recycle loop, where they test the failure, not test the pass, but test the failure. The failure is

analyzed, it's fixed. You go back to the production line and you fix the process. Then the system comes back through again and it goes through the same test sequence and another failure or the same failure is looked at until you finally get that problem worked out. But you don't work it out in just what has been called design, or in a test phase, you use a lot of different test techniques, but you don't work it out just there. You've got to go back to the production line and fix it. Fix it on the production line. That's what it looked like to us and we really believe that that's where most of the problem in avionics is coming from.

Incidentally, that chart and a lot of other stuff is in this publication, if you are interested in it, we can send you a copy.

We found in our analysis of the data that about 87% of the field failures that we saw, we could attribute from our particular set of experience as to production processing problems. We said, all right, what are our lessons now? You can see that the last one is we've got to develop a new philosophy in avionics testing very shortly and I think George Raroha, who is probably not here right now, he was talking about a system, a (?) system that's going to go in an aircraft, that's

going to be coupled to flight control and now you've got an inertial package, an avionics package that's coupled to flight control in perhaps a fly by wire aircarft. If that package goes down, your airplane goes down. The situation is obviously intolerable. We can't accept that kind of thing. We've got to get avionics reliability right up to the same reliability level that you do with an aircraft structure. Well, how do you do that? Well, you break it. You test the aircraft structure way beyond its design goals. You test it until it breaks and then you find out why it breaks and you go back and fix it in your manufacturing techniques, generally. Perhaps you need a new allow or whatever, but in any event you fix it, because when the airplane gets out there, you don't want an airplane flying with a 10% structure.

Well, we've been tolerating 10% in avionics and I think we have probably reached the end. When you start tying that stuff to flight control systems and you're going to kill an airplane with avionics, it's no longer feasible to do it that way. So we are in fact going to have to test avionics to destruction, I believe and fix them back on the production line. Make sure that when you fly that thing, you design it for 750 hours, that's exactly what you're going to get.

And the man in the cockpit really wants to know this. Because the real bottom line is weapon system availability. When you need a flight, you've got to climb in that thing and know it's going to go.

NIEWOOD-SINGER: I wonder if you could put the first chart back on that shows the comparison of the MTBF. I'd like a definition of the acronyms. I don't think you're talking the same two numbers; I may be wrong, so I would appreciate it if you would define what you meant by MTBF spec and what you mean by flight MTBF. How is flight MTBF calculated. I know how MTBF spec is calculated and I think I know how flight MTBF is calculated, and I don't think they are the same two numbers. I wonder if you'd clarify that for me.

SILVA-VECTOR: Well, there's no way really

(DID NOT RECORD.)

LOGUS-ASD: There is a difference and Harry's right. That MTBF spec that's up there is normally meant to be total operating hours versus verified failures. The flight MTBF normally works out to be flight hours divided by squawks or in some cases removals, and that difference alone can account for at least a 4 to 1 difference.

GIDLOW-SINGER: I'd like to agree with you Bob on some of the things and I'd like to take issue on some

of the other things you said, and that is that we definitely need a new philosophy in avionics test to establish reliability numbers, but one of the lessons that I've learned anyhow is that I don't really get heartburn very often anymore over MTBF numbers because I can't really get a good definition and you know we talked about a goal of MTBF's, we say maybe it's 400 hours and that number is indeed based against something and generally it's a lab test of production equipment at some phase in the production of hardware. And the fixes are made in the hardware until you mee that established number.

But someone in their wisdom of procurement has stated that if you can meet that number in the lab, you're going to satisfy the mission requirement and there, I think, is the difference.

SILVA-VECTOR: That's not true, you know.

GIDLWO-SINGER: No,it's not true, but somebody has said that in procurement documents.

SILVA-VECTOR: Well we said reliability may very well be a procurement problem.

GIDLOW-SINGER: Well, it's partly a procurement problem, and it's partly a production problem, and it's partly a test problem and a degree of competence problem and it's many, many problems.

(?) -ALD: The bottom line in the whole issue reads is what is the cost to the Air Force for upkeeping the systems that we do buy. Now, I think Bob said it in the beginning that our basic problem is the procurement strategy. Maybe we should take a firm like Litton and say, okay, fellow, deliver us the systems, we'll set up the test site, we want you to demonstrate 300 hours failure-free operation in environmental conditions and send them back 100 systems and say 3% failed. Psychologically they're doing the same thing to their business.

LOGUS-ASD: I guess we'd better be prepared to be flying with Boy Scout compasses.

McHALE-NAVY: Really the issue is, and I agree with your general conclusions and I don't wish to get involved with these numbers because I'm getting more like the commercial airlines. I refuse to talk almost MTBF. Mean time between removals is about the only meaningful thing and in terms of cost, like you are mentioning up here, the only meaningful thing in the whole -- when everything is said and done, is how many damn dollars it costs per flight hour because we're all here for one and only one reason and that is to give an airplane an operational capability for a certain amount of hours.

That's the only end result of the product. The reason why we exist is not to give AGMC or not to give Litton or North Island or any or all of these people jobs. That's not our prime purpose in life. The purpose in life is to give a cost-effective weapon system and the only way we can do that is to use the yardstick of dollars per flight hour.

SILVA-VECTOR: When you use that yardstick, it's interesting to note GE did some work some years ago and I think Dr. Semans, who used to be Air Force Secretary for you people who are old enough to remember that part, he gave a presentation which -- and I'm not too sure how he came about arriving at these numbers -- but he showed considerable data that said that if you spend one dollar now, you save $10 in support costs later on. If you find yourself a failure and fix it.

The money spent up front, I recognize there is always trouble getting more money to spend up front. But you end up spending infinitely more money, like a factor of ten at least, or a hundred I should say, at least, downstream.

BRANN-LITTON: There is one point I'd like to make. I think it would be a shame -- I've heard the 10% number now about three times today -- and it isn't true across all the board. It's true for some systems. I don't know how many people are familiar with SCHRAM

here, but the Litton IMU that's on the SCHRAM system which is in the B-52 G&H, which is in the Air Force inventory, is a 500 hour system -- between 500 and 600 hours and has been for four years. The mean time between removal, Frank Squires' number for mean time between demand, is over 300 hours on the system. Does anybody here have different numbers than that? That's a lot different than 10%.

LOGUS-ASD: You're right about what it is now, but there is a correction that goes back with the McDonald man. The reason it's 600 hours now, is because we were backed up against the wall. That system was failing so bad we had to back into PRT and PRT happened not by design, but because your system as well as a number of others were failing and people finally said, hey, we gotta do something dramatic. It backed up the production line, it backed up the B-52's and damn near killed SCHRAM program. But, when they did institute it, yes, it did, it made some dramatic changes and that's where we first learned about it. And Norm Palmer is sitting up in front and you were there, right? We had to go TDY to find out about that.

BRANN-LITTON: I was there, too, and I'd like to make a point about that. First of all, I submit and it's easy for us to go check the records that the SCHRAM

system in the field was never less than 300 hours. I was there when it first went up, to Loring. If you go back into your own records, I sumbit to you, we'll go get it and find out. It's never been below 300 hours even including the failures at the integration site at Oklahoma City where they (?) the G&H.

So we'll go check into that. I claim it's never been below 300. So it went from 300 to 500. And 300 is like 50% of spec, not 10%. And it's my understanding and I could be wrong, that Boeing instituted failure-free burn-in across all of the SCHRAM avionics early on in the program, and it was applied to everybody, not just the inertial system. And that's how it was done in the program. Is that true?

PALMER-DRAPER: What I know about it is with respect to the gyro and that had a 90-day storage spec and it wasn't meeting that, never mind running time.

BRANN-LITTON: I'm very familiar with that. There was a mass unbalance problem, if you remember.

PALMER-DRAPER: At that time, you didn't know what it was. Litton introduced a crash program and brought up about 27 different possible solutions.

BRANN-LITTON: But it never got to the field, is what I'm trying to tell you.

PALMER-DRAPER: What never got to the field?

BRANN-LITTON: The problem never got to the field. The system was 300 hours from the first day it hit Loring, first operational site.

PALMER-DRAPER: It was being tested at Oak City. Because there was no test at that time to check it in the field. In fact, Boeing proposed to produce some test equipment if the Air Force wanted to buy it later, to possibly test it out in the field. There was no test.

BRANN-LITTON: Okay, I guess I honestly don't understand the point. I thought the argument was that when you hit the field with the system, operational base, you're talking about a problem that existed prior to delivery and, yes, it was there, and it was solved, etc. But the point is that the aircraft at Loring delivered the first ones from Oak City and Oak City had to do special screening, is that what you're saying, they had to do special screening before they go on?

I agree they did. They went out and flew a pattern and I remember that and that was part of the sell-off of the aircraft. That's how they did it. I still think, and I'd like to check that out, it was 300 hours from the first day at Loring for the program.

THOMAS-SANSO: Well, the 10% rule doesn't hold. I can tell you LN-12, it was specified from 200 to 250 hours, depending on which aircraft it was on, and it gets around 40, so it's more like the rule

of thumb 5 or 6 for the LN-12.

(?) -S-KF: I think what we have just demonstrated is the fact that we don't have a good failure reporting system. And you can talk all you want and we just had a good demonstration here of two gentlemen who were working on the program very intimately and they can't even define what the failure reporting system is.

It seems to me that what we ought to start concentrating on and we've talked about it for two decades between industry and the government, and we've talked time and again about the necessity for improving 66-1 or calling 66-1 what it really is and 3M what it really is.

And if this conference can do anything, it seems to me that we ought to address the right people to help us develop a creditable and understandable reporting system.

The figures we got up here came from GE and another set of figures come from somebody else, but we never can really understand what they mean and we'd better start in this field of inertial guidance with a good failure reporting system.

DENHARD-DRAPER: I ask my standard question. Will all the procurement and contract people please stand up.

HYMAS-CIGTF: Well put.

ZIGONI-(?): Bill, why don't you, since you're the one that's doing it every year, why don't you get a copy of the tape and send this session to them? And hope that they listen.

HYMAS-CIGTF: I think that's a good idea, too. But I suspect I'm the only living person that's ever listened to a tape of this conference. And you should have seen the looks on the AGMC folks' faces when I asked for it.

Well, with that limb that Al has crawled out on, I'd like to turn to the next topic and see how he crawls back.

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<u>TOPIC:</u> FIELD RELIABILITY LOWER THAN LABORATORY DEMONSTRATION RESULTS BY 10:1

<u>WHY:</u> INADEQUATE ENVIRONMENTAL SIMULATION
HIGHER TECHNICIAN SKILL LEVEL IN THE LAB
DIFFERENT REPORTING, ANALYSIS, AND CLASSIFICATION OF FAILURES

<u>LESSONS LEARNED:</u> MISSION PROFILE MUST BE REALISTIC AND APPLY TO ALL PHASES OF THE PROGRAM
MIL-STD-781 REQUIREMENTS SHOULD BE CHANGED TO REFLECT THE REAL WORLD
ADEQUATE FIELD REPORTING MUST BE ESTABLISHED

BRANN-LITTON: I want to look at this because with all of the discussion we've had today, I have a feeling there's nothing here we haven't discussed.

The first item is obviously the CET testing and

the right environmental simulation of the system and later on we'll talk about our CET facility. We also have a combined environmental test facility at Litton, brand new, it'll be on line in a couple of weeks, similar to the one that's at the Flight Dynamics Lab and the lab manager will talk about that in a while, but we do have a combined environmental test facility for use in development, not for rate tooling production, as some people suggest should be done.

Adequate field reporting, yes. I think we've discussed that, too, many times. I think everything that's on this we've covered in other places. Any questions about this?

HYMAS-CIGTF: Ray Clodfelter.

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TOPIC: RELIABILITY DEMONSTRATION TEST

DISCUSSION: THE INADEQUACY OF ML-STD-718B TESTING AS A PREDICTOR OF INS OPERATIONAL RELIABILITY IS WELL ESTABLISHED. FURTHER, THE QUOTATION OF CIGTF DATA AS A RELIABILITY INDICATOR HAS ALSO BEEN SHOWN TO BE INAPPROPRIATE AS THE CRITERIA FOR FAILURE OF A TEST SYSTEM BEARS LITTLE SEMBLANCE TO THE CRITERIA APPLIED BY FIELD UNITS.

LESSONS LEARNED: THE OPTIMUM RELIABILITY PREDICTION TECHNIQUE IS TO UTILIZE ALL AVAILABLE DATA DURING THE DEVELOPMENTAL LIFE OF A SYSTEM. THIS CAN BE DONE BY CAREFULLY SELECTING THOSE PARAMETERS THAT ARE NEEDED TO MEASURE/DESCRIBE SYSTEM RELIABILITY EARLY IN THE DEVELOPMENT PROGRAM AND USING THEM AS A BASELINE OF COMPARISON. IF ALL SYSTEMS ARE JUDGED ON THIS BASIS, AN OBJECTIVE, FAIR EVALUATION WILL RESULT IN A REALISTIC EVALUATION. SUCH AN EVALUATION MAY ALSO SERVE AS A BASELINE TO FURTHER

ASSESS RELIABILITY PROBLEMS AFTER THE SYSTEM IS FIELDED.

CLODFELTER-AGMC: I wouldn't want to touch this one with a ten-foot pole. But let's have the next chart anyway.

We all know that there are many arguments that can be had for what's wrong and what's right with a reliability demonstration test and I'm not going to try to cure all the evils of the world. It's rather obvious however, that most people have rules of thumb about interpreting data which means that there must be some correlation of data, it must be reflective of something if you can put a ratio on it in order to apply it.

The other thing I submit is that whether we like reliability demonstration tests or not, and for all their faults during source selections and later logistic planning we do all make reliability predictions.

So what this chart is intended to imply is that we should stirve toward developing a common base during the entire development of a program and for instance at CIGTF, and this is just as an example, perhaps we should set tentative criteria as to what would constitute a field rejection and incorporate that as part of the evaluation criteria at Holloman. Any questions?

BROWN-ASD: I think the real lesson here is that reliability demonstrations test is a valid tool but the point at which it's invoked and used has been

abused. We've been in the habit of conducting reliability or 781 type testing after we have gone into production and this is a sad point in time to detemine that you have some failure modes and deficiencies in your design.

So there's nothing wrong with the reliability demonstration test, but there's something grossly wrong with invoking it after you've gone into production and that's what we recognize on the F-15 program and we eliminated the requirement because we were not able to pass it at the appropriate point in time.

But I submit that the requirement should not even be to pass the test. The test is to be used as a tool to determine where you are and where you are going and it should be invoked at the development of the system, and not after you've built it.

LOGUS-ASD: Bob Silva made a very good point previously about we should test the fail, because the problem we run into with the 781 is we're so mesmerized with passing that we pass or rather we take enough of the failures and count them as non-relevant, enough to make the thing pass. It's great. You look at a test and you say well there's 36 failures over 1500 hours and we go through one by one ticking them off until we get down to one failure and we say, ah, they were all non-relevant with the exception of this one. As my previous boss said, the only mistake with that was

that we should have also counted that as non-relevant.

THOMAS-SANSO: If I understand some of what some of the people are saying, part of our reliability is in the production line, so there's got to be an evaluation of when we go from the hand-built piece of equipment to the one that goes through the production line. We've somehow got to figure out what kind of reliability we're now getting out of the production rather than we got out of the prototypes.

BROWN-ASD: That's just the precise point that I was trying to make is that we recognize that the reliability demonstration test is not used for that purpose. We went to an all-equipment burn-in test where we assess the reliability on every item as it comes off the production line. I might point out that we went from about 30 hours mean time between failure to where we are over 300 hours now and that attests to its success. I think you've also recognized today that Litton is sort of sold on the idea.

O'NEAL-ROCKWELL: The rest of that problem is that very often when we're in the design phase and developing your system, you are developing the parts and they are not ready to be evaluated for the reliability yet.

HYMAS-CIGTF: Okay. Turning to the next topic, one of the ways that we will get involved in

evaluating reliability or estimating it, I assume, will be some form of combined environment tests. Captain Von Husen has an item here just to help us with the lingo a little bit.

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TOPIC: CERT TERMINOLOGY
CERT: COMBINED ENVIRONMENTS RELIABILITY TESTING
CET: COMBINE ENVIRONMENTS TESTING

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|---|---|---|
| FEASIBILITY CERT | - | IS CERT A GOOD TEST? |
| DIAGNOSTIC CERT | - | TROUBLESHOOTING SYSTEMS IN THE INVENTORY |
| DESIGN EVLUATION CERT | - | IDENTIFY DESIGN DEFICIENCIES, TEST AT ENVIRONMENTAL EXTREMES |
| RELIABILITY EVALUATION CERT | - | ESTIMATE RELIABILITY, TEST AT EXPECTED ENVIRONMENTS |
| COMPARISON CERT | - | ESTIMATE RELATIVE RELIABILITY, TEST AT EXPECTED ENVIRONMENTS |

VON HUSEN-CIGTF: Last spring the CIGTF was tasked with the job of assessing the value of implementing CERT into the verification tests. After taking a look at the situation what we had in lab facilities, and the like, and talking to a number of individuals, I couldn't get a good handle on what CERT is. Everybody that I talked to had a different opinion. Not only at the CIGTF, but talking with Newark Air Force Station and the Flight Dynamics Lab.

You had as Buddy presented earlier, with those ASN-90 units, that was a diagnostic CERT. Then you have what they call a CET type of program. And we had to

go through a complete determination of what Flight Dynamics Lab was doing, the feasibility CERT. Is it actually feasible to do this type of testing. CERT sounds good, but really as of today, it has not yet completely proven itself as an adequate method of checking the system. I hope that the results that come through the Flight Dynamics Lab turn out very positive on this.

HYMAS-CIGTF: Let me just interrupt you for just a second, Ray. Do you want to tell them what CERT stands for to begin with and then CET?

VON HUSEN-CIGTF: Well, I'm trying to get into this thing as a point that since I'm using the word CERT and CET without a definition, I can show you how the confusion keeps working up into this situation.

But since you brought it up, combined environments reliability testing is the definition of CERT. CET is just combined environments testing, dropping the reliability part out of it. Reliability will come into play through the use of the test, but later on.

Now, after all the dust settled, there was these five different definitions: the feasibility, which the Flight Dynamics Lab was doing, along with AGMC; the diagnostic CERT, which was primarily again the Dynamics Lab working with AGMC and what was presented by Mr. Buddy Bleichroth.

Now, the last three is what we are looking at from the CIGTF. Design evaluation CERT. Now this is primarily CET, just combined environments testing. That is exercise the system to its design limits for a short period of time. This is a short test possibly maybe a 100 type of hours and 100 hour range.

Then you've got reliability evaluation testing. This is to pin a reliability number on an inertial system. I don't like to use that term MTBF. After that last conversation I'm a little bit leery of standing up here, but pin some type of reliability index number on the system.

The last one is a comparison CERT. This would take less hours than a reliability evaluation, but it wouldn't pin a specific index on a system. It's comparing two systems; one against the other, saying in this type of environment system A is more likely to be more reliable than system B and this would take a shorter number of hours.

With the reliability evaluation CERT, you need to have the specific environment that you are talking about, the specific airplane, the specific location, the vibration, temperature, humidity, and the altitude range. Or that specific aircraft.

In a comparison CERT, you take a typical, a

fighter aircraft profile, a cargo aircraft profile or a helicopter profile, and you compare the systems in that profile.

Now, I think I've covered those five. Are there any questions? This should bring out more on it.

HYMAS-CIGTF: Okay, appreciate it, Ray. Cleared it right up. I thought that Dr. Burkhart from Flight Dynamics Lab, who is heavily involved in CERT testing there would be here. In fact I leaned on him as hard as I could to be here and it didn't do any good.

VON HUSEN-CIGTF: This is primarily for the contractors. I heard mentioned that some of them are picking up CERT facility type things. They should plug in their definition of CERT into this total picture so that everybody has a good set of ground rules to know what is being talked about with CERT.

HYMAS-CIGTF: Thank you, Ray. It was with Dr. Burkhart in mind that I made up that slide that you saw.

With that introduction, we'll go to Litton again for combined environment testing. I don't know who's going to talk this time.

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TOPIC: COMBINED ENVIRONMENT TESTING

DISCUSSION: ONE OF THE REASONS FOR THE GREAT DISPARITY BETWEEN THE MEASURED FIELD RELIABILITY AND LABORATORY TEST RESULTS IS THE DIFFERENCE BETWEEN THE ENVIRONMENTAL EXPOSURES IN THE TWO AREAS. COMBINED ENVIRONMENT TESTING HAS TOO OFTEN BEEN DISMISSED AS TOO COSTLY AND/OR BEYOND THE STATE OF THE ART. EQUIPMENT IN THE SERVICE ENVIRONMENT IS ALMOST NEVER EXPOSED TO A SINGLE ENVIRONMENTAL FACTOR BUT LABORATORY TESTS ARE ALMOST ALWAYS PERFORMED IN THAT MANNER.

LESSONS LEARNED: CAPABILITIES DO EXIST AND COMBINED ENVIRONMENT TESTING CAN BE ACCOMPLISHED. RESULTS OF SUCH TESTS SHOW MUCH BETTER AGREEMENT WITH FIELD RELIABILITY EXPERIENCE.

(?) -LITTON: Thank you. Al said most of it. The topic of combined environmental testing. That's nothing new to this group. Those of you who were in San Diego last year will recall that there was quite a bit of discussion by the Flight Dynamics Lab and by the Litton personnel.

I would like to read the discussion. One of the reasons for the great disparity between the measured field reliability and laboratory test results is the difference between the environmental exposures in the two areas. The combined environmental testing has too often been dismissed as too costly and/or are beyond the state of the art. The equipment in the service environment is almost never exposed to a single environment, but rather is never exposed to a single environmental factor, but laboratory tests are almost always performed in that manner.

Now, I wanted to go over the lessons learned and then go to the second chart. The lessons learned are the capabilities do exist and combine environmental testing can be accomplished. The results of such tests show much better agreement with field reliability experience.

Now, if I could go to the next chart, please. Litton has procured and installed a combined environmental test facility for developmental testing on some of our programs, such as our missile program and the F-18 program. The chart that you are seeing is the chart that we presented in the early stages of our development and the specs. I would like to make some corrections as I go along.

We have a temperature range in the chamber of -100 to +200 and that should be 15° C per minute, for the rate of change. We can do 15° C per minute going up, we can do about 13° C per minute coming down. That's with LN-2 boost.

We can do humidity from 20% to -- well, it goes off the chart, 99.9. We can do vibration. We chose those numbers assuming a fairly heavy load. They are certainly more than I think you'll ever see in an aircraft in the real world. We can go 5 to 2000 hurtz, we have the capability for both random and sine.

Altitude, we specced it from site level to 70,000 feet, we checked it last week up to 90,000 feet. That's with the shaker in place underneath.

We are pooling our capability for the prime equipment which is under test and we go from a half pound, not a pound, a half pound, up to eight pounds per minute and that's over the entire altitude range. We can go from -65 to +200, and we can do about 15° C per minute. We are still working on that. We're just about a week too soon. I don't quite have all the numbers. Some of the tests are still being run.

We can also provide humidity in the cooling air and one thing that was not on this chart, which has been added, we have the software capability now, we can do shock.

This equipment is on line and is being tested now.

I think again the lesson learned is that combined environmental testing is very -- can be accomplished.

The payload of the chamber itself is about 75 cubic feet. We had typically talked about staying with a two-box system. Round figures of 60 to 100 pounds. But again, that's variable, depending on the fixture.

CLODFELTER-NEWARK: It's not particularly addressing the specific chart, but concerning combined environmental testing. I think some people this morning indicated that they believed that the length of flight and the on and off cycles had something to do with reliability. Has anybody incorporated that into the combined environment?

BRANN-LITTON: The integrated test plan we mentioned on the F-18, NAVAIR and MACAIR asked us to specifically include the total number of on/off cycles that we get, estimated, as well as the total operating time and it's in the thousands of on/off cycles that we will get.

And the mission profile for this CERT facility will include the various mission profiles like you were talking about before. We are simply going to take the mission scenarios from MACAIR for example,on F-18. We are going to model them and then we are going to decide how big a sample we need. Let's say we do 20 taxi, take-off, rate of climb, we are usually in an unhabited environment. Before, someone was mentioning the fact that they didn't understand how a system could get that kind of rate change. It turned out when a fighter in an uninhabited environment goes off at a base like Langley with a lot of water and climbs at a

very high rate of speed up to 70,000 feet. Amazing things happen at a CERT facility. Water gets in heat exchanges and freezes and blocks and lots of things happen that really happen in the aircraft, but is impossible to duplicate at the organizational level.

But the answer to the question about the on/off cycle is yes, the on time in that CERT facility ought to be exactly what it's going to be in the mission profile, especially when you've got all that investment of capital to duplicate everything else, it would be crazy to let it sit there and leave it on all the time.

(?) -LITTON: I might add that I have a meeting tomorrow morning at Wright-Patterson with David Earls and Dr. Burkhart just on those kind of subjects.

What did we learn? We're putting it on line now. We -- no. And it's very heavy.

(QUESTIONS FROM AUDIENCE NOT USING MIKE.)

BRANN-LITTON: We didn't go up and do this because we got an RFQ that said would you guys do CERT if you had one, cause it's kind of expensive. So we worked with Burkhart for a year and I actually looked at the data he ran on the A-7 program and he went out and he did instrument an aircraft, as it was pointed out, and used the actual mission environmental stuff, and the correlation

he found between the CET data and the field data was pretty good. If he was getting a 70-hour MTBF in the field on a particular box, he was getting 70 hours in the combined environment. But the only thing you can't do, obviously, is accerlation. This thing weighs tons and so it's not going to be a perfect correlation.

So our assessment was that it is real. It will work as a tool. But you are right, we don't have the data yet.

The second part of the thing that's nice about that is since it's a really good combined environment, it should shorten developmental schedules, because now that you can actually model the mission profile better, you don't need as much testing. Now that's what will probably come out. I've noticed that most of the RFQ's that have CET testing option show a much shorter period of time because you're not walking from the humidity chamber to an altitude chamber to a vibration table, so you can get off quite a few flights in a shorter test period.

But as soon as we get actual test data on the programs, we'll share it at the next meeting. That's a year away. We'll have considerable data before then.

But we will be sharing it and putting papers into the various symposia as we get test results. But to my knowledge, we're the first system house to have them.

HYMAS-CIGTF: I have a question for you on that. Do you have a contract requirement to conduct CERT?

BRANN-LITTON: Yes, we do.

(Questioner did not use mike.)

HYMAS-CIGTF: I have one more question for you. Did you make that investment based on Burkhart's test?

BRANN-LITTON: Yes, we made the investment on the assessment that it was going to come and be real so we decided we'd like to be one of the first to do it.

HYMAS-CIGTF: Since we consider his results incomplete at the present time.

BRANN-LITTON: (Did not use mike.)

(?): I'd like to make one comment to the gentleman over here. A year ago in San Diego at this meeting, although there was a lot of discussion and there was a lot of negative comment and a lot of negative thoughts, so again, going back to the lesson learned, we have demonstrated -- we are demonstrating that combined environmental testing can be accomplished. It has been accomplished. We have a piece of equipment on line. Capability, price, whether the state of the

art, and it's now a real item.

HYMAS-CIGTF: I'd hate to do such a good job at this today that I'd have to do it again; that is, get through all the topics in the alloted time, so I suggest we terminate at this point.

INSTRUMENT GAS AND BALL BEARINGS LESSONS
LEARNED WORKSHOP
CHAIRMEN

COLIN C. T. MILLARD
BRITISH AIRCRAFT CORPORATION
ENGLAND

ROBERT J. SCHIESSER
CHARLES STARK DRAPER LAB
CAMBRIDGE MA

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SESSION IV

INSTRUMENT GAS & BALL BEARINGS

LESSONS LEARNED

WORKSHOP

THURSDAY, 27 OCTOBER 1977

CO-CHAIRMEN: ROBERT J. SCHIESSER,
CHARLES STARK DRAPER LAB

COLIN C. T. MILLARD
BRITISH AIRCRAFT CORPORATION

SHERATON INN

really is what might be called (?) There's no apologies for that, because I don't think any one person here can honestly say they haven't seen the same problem at least twice in their facility.

I think perhaps in general then, lessons learned might well be retitled to "lessons apparently haven't yet been learned." It will be interesting to see, say, in the next three years whether the same problems and solutions are being discussed.

We can get on with it. This was in fact submitted by the Admiralty (?) Observatory in the UK. I haven't really much background knowledge of it, but if you people would like to read it, if you have any questions, I will help out.

TOPIC: CHEMICAL VAPOR DEPOSITION OF TUNGSTEN CARBIDE FOR GAS BEARING SURFACES

DISCUSSION: SUBSTRATES OF NITRIDED STEEL, 65% NICKEL AND 30% NICKEL ALLOYS, IN THE FORM OF SHAFTS, THRUST PLATES AND CONES HAVE BEEN COATED WITH TUNGSTEN CARBIDE IN THICKNESSES OF 5 TO 100 mm. HARDNESS GREATER THAN 2000 VPN HAVE BEEN ACHIEVED. HOWEVER, SURFACES SHOWED NODULAR DEFECTS, PARTICULARLY BAD IN THE STEEL, AS WAS ADHESION. INTERNAL STRESSES ON SINGLE SIDE COATED THRUST PLATES CAUSED PROBLEMS - WHEREAS COMPLETELY COATED SHAFTS AND CONE GAVE GOOD RESULTS.

LESSONS LEARNED: TO IMPROVE ADHESION ON STEEL SUBSTRATES AND REDUCE NODULE FORMATION, AN INTERLAYER OF VAPOR DEPOSITION MAY BE CONSIDERED A VIABLE ALTERNATIVE TO FLAME DEPOSITED COATINGS.

MILLARD-BAC: Okay. I think it's self-explanatory,

but any questions from the floor?

GARDOS-HUGHES: When you put down hard coats, whether it's chemical vapor deposition, or you spot ring or iron plating or reactive spot ring, you have a real problem with stresses building up in the covering, if it's too thick. You have spalling, you have beetling, so actually if you have a real good hard coat and you don't have any problems with coefficents and thermal expansion mismatch, you'd prefer to have something thinner. I don't understand. I'm sure you had your reasons, I'm sure you tested it, but I sure would like to know the reason for success.

MILLARD-BAC: All I can say is I echo your sentiments. Certainly literature would agree with you. I've no experience with this particular program, since this was carried out by a different agency. I'll certainly take back your comments to the UK and ask them if they have anything to say on the subject.

SCHIESSER-CSDL: We have had some success, although limited, at the Draper Lab with not vapor deposition, but reactor vapor deposition coatings up to a few thousand thick, a thousand or so, on flat plates. We have had some success with coating tungsten carbides in cobalt matrix to 50 or 60, and possibly 80 microinches.

We've had no experience though at the lab with vapor deposition, but we've had coatings as deposition.

GARDOS-HUGHES: Did you have to machine after depositing such a thick layer and if you did was there a machining method that you used to make sure that you don't have any surface cracks remaining on the surface after machining?

SCHIESSER-CSDL: Yes, in fact the reason that we went to thick coatings is because we felt it was necessary to finish the surface after deposition and the finishing method was lapping.

MILLARD-BAC: Okay. I think we are ready. This is from Pete Jacobson, Sperry-Flight System.

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TOPIC: OIL BLEED RATE TESTING FOR POROUS BALL CAGE MATERIALS FOR GYROSCOPIC SPIN BEARING APPLICATIONS.

DISCUSSION: LUBRICANT BLEED RATE TESTING OF POROUS BALL CAGE MATERIALS PROVIDE IMPORTANT DATA RELATED TO ULTIMATE PERFORMANCE OF A PARTICULAR MATERIAL IN THE SPIN BEARING OF A HIGH PRECISION GYROSCOPIC INSTRUMENT. THE MEASUREMENT OF THESE BLEED RATES, HOWEVER, WILL PROVIDE REPEATABLE AND DEPENDABLE RESULTS ONLY IF CERTAIN PRECAUTIONS ARE OBSERVED. IF THIS DATA IS NOT TAKEN PROPERLY, THE RESULTS WILL LEAD TO MISLEADING CONCLUSIONS, IMPROPER APPLICATIONS, AND GYRO PERFORMANCE PROBLEMS.

LESSON LEARNED: WHEN PREPARING BLEED RATE TEST SAMPLES, THE MATERIAL MUST BE CONFIGURED EXACTLY AS THE ULTIMATE PART AND MUST BE FABRICATED, CLEANED, LUBRICATED AND STABILIZED TO SAME SET OF CONDITIONS AS INTENDED FOR THE END APPLICATION. MACHINING, LOADING OF LUBRICANT, AMBIENT CONDITIONS, MUST ALL BE CAREFULLY CONTROLLED TO ACHIEVE THE

PROPER DATA. REPRESENTATIVE BLEED RATE DATA IS VERY REPEATABLE WITH A SYNTHESIZED HYDOCARBON LUBRICANT MANY RETAINER MATERIALS, SINTERED NYLON, POLYIMIDE, AND PHENOLIC, THE TIME DEPENDENT BLEED RATE DECREASING WITH INCREASING TEMPERATURE. MICROPOROUS COPOLYMER MATERIAL RATE INCREASES WITH INCREASING TEMPERATURE. OIL BLEED RATE DECREASES WITH INCREASING VISCOSITY (30 - 80 CS AT 100°F).

JACOBSON-S-FS: For some number of, or about two years now at Sperry-Flight Systems in the bearing lab, we've been doing some research on porous cage materials and then trying to correlate the results of that with spindle testing of bearings and (?) cycle testing of wheels. And we found out that there is an infinite number of ways that you can take data that you can't use, so we've put together some of the ways that you can take data that gives you much better correlation and we thought we'd just go through these quickly this morning.

For one thing, when you build up this test specimen it's imperative that it be configured in exactly the way it is loaded in the bearing. In other words, the centrifugal loads, the temperatures, the ambient, all of the forcing functions on that cage must be duplicated. And when you make the test samples, then the vacuum impregnation, which creates some pretty healthy driving forces to put the lubricant in the bearing must be exactly as those are for the end application. You can't use one set of specifications

for putting the oil in and another set for making the final bearing.

Also when the bearing is loaded, it must be centrifugally loaded in the radial direction. This means one technique is to spin the cage at its normal spin rate. It must be loaded in a nitrogen environment, if it runs in nitrogen. If your labs are like ours ~~are~~, it runs from 40 to 60 percent and then in the spring, it drops down to 10 percent and goes through two cycles of 10 to 60 percent and this can really screw your data up. So it must run continuously in an ambient that is inert.

One other thing we found that really improved the test data is by taking a dry sample of each of the materials that are being evaluated -- and we're evaluating about eight now -- you can start off by taking a vacuum baked dry cage and put this in an oven and then pop that door open, take the cage out, and run on a dead run to the (meddler?) and put it on there and determine the ingestion rate of humidity. From that curve, you can come up with a probable time to get a probable weight error. We find that to get 1/10 of a milligram takes about two minutes. And that

means we almost have to jog to the metaler, which is about 100 feet away and get on zero and take a reading and get off.

When oil is in the bearing, it decreases that sensitivity but that gives you a built-in margin when you determine the time that way.

Also, when the material is, let me give you, to make this short, let me give you a guideline we find very handy. For materials like Nylasint 64HV3, HV2, the duPont and the Dixon and the Hughes porous polyimides, and the Sinthan Taylor porous phenolics, standard phenolics and the Hughes porous phenolics, all of these materials have a bleed rate that decreases with increasing temperature for a great range of the synthetic and the non-synthetic countercarbons. Like range, I mean viscosity ranging from like 30 CS up to 160 at, what is that, 100° SOG 160 and so forth, that's 160 CS roughly at 100°.

Also the influence in a microporous polymer is exactly the opposite, it increases the bleed rate with increasing temperature. Even though viscosity is not a parameter of bleed rate, it does lend itself to predicting what will happen with bleed rate. Increasing viscosity in the synthetic countercarbons again over that viscosity range will give you a decreased bleed rate. Again, not because viscosity controls bleed rate.

If you think about the fact that increasing temperature gives you decreasing bleed rate, you recognize that the bleed rate is more strongly a function of the cage material than it is the lubricant, because your intuition will tell you the opposite. So that's kind of interesting and tells you what the sensitivity would be from material to material.

If you'll put on that next slide. I hope you can read these. They are pretty crude. We took laboratory data and I want to show you some interesting things here about the way different materials behave.

This happens to be Dixon polyamet .6 micron 4 size and it shows the bleed rate with time. You notice it hits asymptotically a value of about a half a milligram after one hour and the .01876 is the oil content in that R4 cage so that if you cross that line with time, you've taken some bad data.

Humidity effects tend to drive data points below the norm curve. So because we're not doing a prefect job on humidity, we reject curves that are below the line and very rarely do we get numbers above and that means it's a reading error.

Now, even though that corner that it turns is not really that sharp, there's some reading errors in there. Notice how small that quantity is. When you have numbers

that low, you must also do two other things. You must take evaporative loss at each temperature and we run 25, 50 and 100°C and it gets increasingly important as temperature increases to take a bleed rate, or, I'm sorry, to take a evaporation rate and normalize these curves. This happens to be 50C. So I must depress the position of this curve with evaporation so that the data points are really below the curve. Now to do that you must also put in the same area of the volume ratio that the lubricant sees.

Here's something very interesting that we found. Maybe you know it already, but we didn't. The small amount of oil there says that if there is any disturbance of the cage in its normal operation you could very easily dispell that oil. That curve tells you that that's what we call a starved bleed rate condition. If you, say, have a dynamic instability at ten hours, you will deplete by this violent action part of that total quantity of .5 milligrams. Now, also if you take the bearing out of that assembly or flush it after it's run more than one hour, you've depleted its lubricant supply.

Back to the evaporation condition, you find that the oil film evaporates significantly slower than the oil in the cage because the area of the volume is

different. That ratio for this particular assembly is about 8 to 1.

Let's go quickly through these three. This is an example of an undesirable condition. You notice it hits that line asymptotically at only 200 hours and the next curve is what we call an ideal bleed rate. Okay. This is more in the norm You see the two humidity drops. And the next curve is a data point of evaporative loss from a cage where the area of volume is high and you notice it crosses there at 100 hours at one milligram.

This is the same oil, the same temperature as an oil film. You notice it takes it eight times longer to cross that point. So when you normalize the curve, you must take evaporative loss exactly as it is in the operating bearing.

Okay, that's a lot in a real short time. Do you have any questions?

SINGER-DRAPER: Pete, did you take into account the machining differences you may have gotten from material to material, especially with porous material where you can seal off the pores and also pre-treatment if you machine with any oil impregnated in the slug before you machine it, would that affect the surface tension between the RL-743 and the material from one

sample to another sample?

JACOBSON-S-FS: Okay. Starting with the pore sealing, we find, and this is a little different than we have heard reported, we find that there is very little change of bleed rate brought about by good machining all the way to poor machining of the materials on the order of one micron 4 size. I realize I'm saying something that's not exactly what a lot of us have heard before but we believe this to be true. Because it only takes one of these many surfaces with the right kind of pores to give you a bleed rate, say, in a given category. It's improbable that all surfaces would be poor. I guess it has happened that some machine techniques are so overall poor that all the surfaces are sealed. But by and large, the great majority of all the samples that are machined have one surface that provides the bleed rate. It's like a bucket full of water rotating on a rope and you've got a one-inch hole in the bottom and you are studying the influence of changing the size of the hole next to the one-inch hole from one-thousandths to ten-thousandths of an inch. It's that large hole that's going to govern it. This was a revelation to us and that's not to say that maching is not important but we feel like the bleed rate is not as influential as has been said previously. And the same is true,

on line. Capability, price, whether the state of the



by the way, of pore size. I'm kind of a rebel in this regard and I'd like to get some feedback and we can't do it here,but I'd like to sit down with people like yourself, Herb, and I've already done it with a number of others and go over some of this data because it does make a difference at what you spend your effort on.

We don't allow, in regard to your other question, we don't allow strange lubricants to get into the cage during the machining process. If there is a lubricant added, it must be not only the same family, but the same viscosity and we've run tests, which I'm sure a lot of us have, to determine the weight loss time to find out how long you must clean if you use (?) or ultrasonic at different temperatures to really extract all that strange oil. It's upwards, it's toward an hour in most cases. Did I smash through those three questions okay?

MILLARD-BAC: We'll have to call a halt at this stage. Okay, thank you. Bi-Level Torque Problems now from Ralph Crooke, I'm sorry, Northrop.

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<u>TOPIC:</u> BI-LEVEL TORQUE DURING LONG TERM DYNAMOMETER TESTING GYRO: MOD 2 IRIG (BALL BEARING).

<u>DISCUSSION:</u> SHORTLY AFTER THE BEGINNING OF DYNAMOMETER TESTING ABRUPT TORQUE CHANGES RANGING FROM 200 TO 800 DYNE CENTIMETERS WERE EXPERIENCED.

THESE TORQUE CHANGES LASTED FOR VARYING PERIODS OF TIME AND HAD ALWAYS BEEN ATTRIBUTED TO EXCESSIVE OIL IN THE BEARING RETAINER, INVESTIGATION REVEALED, IF ANYTHING, A MINIMUM AMOUNT OF LUBRICANT RATHER THAN AN EXCESSIVE AMOUNT AS HAD BEEN EXPECTED.

A DIMENSION CHECK OF THE RETAINER REVEALED THE FACT THAT GEOMETRY HAD CHANGED. ALTHOUGH THE RETAINERS WERE INITIALLY WITHIN DRAWING TOLERANCE, RETAINERS AFTER DISASSEMBLY EXHIBITED OUT OF TOLERANCE ROUNDNESS READINGS.

<u>ACTION TAKEN</u>: ADDITIONAL STRESS RELIEVING CYCLES WERE INCORPORATED INTO THE NORMAL MACHINING CYCLE. THIS WAS ACCOMPLISHED MECHANCIALLY BY CENTRIFUGING AND AGITATION. IN ADDITION THE RETAINERS WERE HOT SOAKED IN LUBRICANT OIL AT TEMPERATURES BETWEEN 200 TO 250°.

CROOKE-NORTHROP: Good morning. This is a phenomenom, if you read this, that we discovered in machining of retainers or cages in that there were locked in stresses in the Nylasint and we took the SIG 160, which is the impregnation oil and gave these a stress relief at about 200, maybe 230 degrees for an hour, prior to a final machining cut. We do have a considerable distortion in some of the retainers and we had (?) condition. This seemed to relieve it. Now, a perfect retainer, even though it's been stress relieved doesn't say it can't be unstable. Is there any questions?

McHALE-NAVY: In the -- what was the axis of the torque meter, your torque tester? Vertical or horizontal?

CROOKE-NORTHROP: These were actually tested immediately in the wheel. This was a function of the wheel

on a dynamometer showing you a bimode anywhere from 200 to 800 dyne centimeters.

MILLARD-BAC: Okay, are we covered on that one? Fine. Tom Blankenship from, I gather this is NARF -- sorry, I can't get around these acronyms right.

BLANKENSHIP-NARF: Naval Air Rework Facility, Norfolk.

TOPIC: YIELD OF G200 BEARINGS ON LOW SPEED DYNAMOMETER

DISCUSSION: G200 BALL BEARINGS WERE CLEANED AND INSPECTED IN CLASS 1-- CLEAN ROOM, THEN CENTRIFUGED AND LSD TESTED IN CLASS 10,000 ROOM BY A VARIETY OF OPERATORS. CLEANING TIME WAS AT LEAST FOUR HOURS PER 10 BEARING LOAD. YIELD AVERAGED 60% AT LSD.

PROCESS WAS CHANGED TO PERFORM ALL OPERATIONS IN CLASS 100 ROOM BY ONE OPERATOR USING CSDL SPIN FLUSH FIXTURE FOR CLEANING (APPROXIMATELY TWO MINUTES PER BEARING). AVERAGE YIELD INCREASED TO 99%.

LESSONS LEARNED: FOR OPTIMUM BEARING PROCESSING AVOID EXCESS HANDLING, USE TRAINED OPERATORS AND PROVEN FIXTURING IN CLEAN AREAS.

BLANKENSHIP-NARF: You can basically read this. The main problem that we had was that we were taking during the first when we said that we were inspecting them in a class 100 room, they were being taken all the way apart to the balls, and then they were cleaned and put back together which greatly degraded the bearing. so after we went to the spin flushing fixture which just sits the bearing on the top, it went to 99 percent. Is there

any questions?

FREEMAN-DRAPER: . . . experience with these bearings,because this is simply a yield test at the initial stages.

BLANKENSHIP-NARF: Right. This is done before it's installed on the wheel. We went to the new Air Force bearing and we are having real good luck with it I think they're calling 500 hours.

FREEMAN-DRAPER: I'm just wondering what sort of experience you are seeing in the field or in the fleet?

BLANKENSHIP-NARF: The feedback we get, it's very hard to trace a bearing, but now that we're doing it this way we don't have any kind -- we used to have a lot of trouble with (?) loss of the pre-loads, and we don't have that anymore. So we seem to be having good luck.

MILLARD-BAC: Okay, Bill, thank you. Herb Singer, CSDL.

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TOPIC: SURFACE CONTAMINATION

DISCUSSION: THE BEARINGS PURCHASED FOR THE OAO PROGRAM HAD EXCELLENT GEOMETRY AND FINISH, BUT THEY FAILED IN A VERY SHORT PERIOD OF TIME. UPON INVESTIGATING THE BEARINGS, IT WAS FOUND THAT THE BEARINGS WERE NON-WETTING TO OIL. IT WAS ALSO FOUND THAT THE RACEWAYS WERE ABLE TO BE ETCHED IN THE WEAR TRACK, AFTER RUNNING, BUT NOT OUTSIDE THE WEAR TRACK.

LESSONS LEARNED: THESE BEARINGS WERE CLEANED WITH JOY DETERGENT PRIOR TO PASSIVATION: JOY HAD BEEN USED IN PREVIOUS BEARINGS WITH NO PROBLEMS. BUT, WHEN DETERGENTS WERE MADE TO THE BIODEGRADABLE PROCTOR AND GAMBLE CHANGED THE COMPOSITION OF JOY. THIS CAUSED A SURFACE CONTAMINATION OF THE RACE-WAYS. OTHER BEARINGS WERE CLEANED WITH REAGENT GRADE SOLVENTS, PRIOR TO PASSIVATION. THESE BEARINGS HAVE EXHIBITED MANY TENS OF THOUSANDS OF LIFE: 3 GYROS ARE OPERATING SUCCESSFULLY IN ORBIT FOR 5 YEARS.

SINGER-CSDL: This is what I consider a classic. It brought up a lot of lessons learned and I just put one of them. I'll discuss the other one.

It put us on the road, and those who know us, know I'm a great exponent for surface chemistry being a major cause for ball bearing failure and probably gas bearings also. And this is one of the ways bearings can be contaminated. We received a group of bearings for the OAO program, with excellent geometry, and I mean excellent. There were no tolerances greater than 20 microinches and the cross race curvature was almost perfect if you take a trace across the curve. The finish was excellent, very little, if any defects could be seen on the races. Yet, when we ran the bearings, within hours, I mean 24, 48 hours, the bearing would fail. And it was characterized that the races were not wetting to the oil. Also in doing a metallurgical examination when we etched the races, lo and behold, the only place that etched was in the wear track. Outside of the wear track area, it was impervious to the acid etch that

would etch normal -- by the way this was 440 stainless steel. It was found that during the passivation process as been know at that time, and maybe still now, detergent is used to clean metal parts. At that time and previous to this time, Joy, household Joy, was a common detergent used by that manufacturer to clean the parts. Well, if you remember back in the early '60s,Congress decreed that all detergents would be biodegradable. Proctor and Gamble was selling Joy to dishwashers and they didn't really care when they changed the chemical composition that they kept the same name.

But whatever they put in it and we found out later in the program what caused the problem, but that's another story. The material attaches itself to the race and during the passivation caused the bearings to be poor-running bearings even though all external characters of the bearing were great. While other bearings of the same lot prior to passivation was stopped and cleaned only with reagent grade solvent and these bearings have given us tens of thousands of hours; in fact three gyros with these bearings have over five years of operation. I've got three sets back in the lab that over 100,000 hours. Last December they passed 100,000 hours.

So there's two lessons learned here. One, we strongly recommend nothing but reagent grade solvents touch the bearing after the final metal removal. And

MUST ALL BE CAREFULLY CONTROLLED TO ACHIEVE THE



two, is the general problem of surface chemistry. Surface chemistry can affect the characteristics of a running bearing.

MILLARD-BAC: Thank you. Do you have any questions?

FRAMM-DELCO: It looks like a nice piece of detective work, Herb. How did you catch the Joy?

SINGER-CSDL: That took a while. We spent a lot of time and effort. This is when we got into surface chemistry must affect the races. And we went through the same old thing everybody does with bearings, change balls, wash the races with solvents, but when we hit the fact that they etched only in the raceway, this really bothered us. We got back to the bearing manufacturer; what did you use to clean the part? And we got all the way back right into a commercial product, Joy, which was used previously on bearings that we had had great success with. But it didn't dawn on us that they changed the composition because of the biodegradable law. Eliminating that, the problem went away. But the problem is always going to be there if we don't watch the solvent both at the bearing manufacturer and also at the user. The user can screw up the bearings just as easily.

MILLARD-BAC: I'll take the co-chairman's prerogative there and say amen.

application. You can't use one set of specifications



CROOKE-NORTHROP: Normal lapping of the races and so forth, would that prevent this particular?

SINGER-CSDL: Depending on the material that is lapping. Passivation is a process done after the final metal removal. So they lap the races, actually, these were honed. But they final machined the races by honing and lapping and then they went to the passivation. The lapping, the material used in the lapping compound, especially the materials that have a large percentage of silicone in it, would attach itself to the material in the races and cause problems.

MILLARD-BAC: Vin Orlando, then, please.

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TOPIC: GROOVING GAS BEARING WHEELS BY GRIT BLASTING

DISCUSSION: THE PROPER OPERATION OF SELF GENERATING GAS BEARINGS REQUIRES GROOVES TO BE APPLIED TO THE BEARING SURFACE. ON CERAMIC MATERIAL, A COMMON PROCESS FOR APPLYING THE GROOVES IS TO DIRECT A HIGH VELOCITY STREAM OF FINELY DIVIDED ABRASIVE MATERIAL ONTO THE BEARING SURFACE THROUGH A MASK. POSEIDON GYROSCOPE WHEELS OF SOLID ALUMINUM OXIDE WERE GROOVED IN THIS WAY. THE LIFE OF THE WHEELS, PARTICULARLY DURING MANUFACTURING CYCLE, WAS VERY LIMITED. AND EXTENSIVE STUDY INTO THE CAUSE OF THE FAILURE WAS INITIATED.

LESSONS LEARNED: THE STUDY REVEALED THAT THE GRIT BLASTING PROCESS LOOSENED PARTICLES REMAINED IN THE SURFACE OF THE BEARING EVEN THROUGH THE STRINGENT CLEANING OPERATIONS. HOWEVER, AFTER A PERIOD OF OPERATION, THE PARTICLES WOULD BECOME FREE AND WOULD ABRADE THE SURFACE OF THE BEARING FORMING ADDITIONAL LOOSE PARTICLES. THIS LOOSE DEBRIS HAS BEEN CLEARLY SEEN IN THE BEARING USING THE SEM AND WAS CLEARLY THE CAUSE OF EARLY FAILURE.

PROCESS FOR APPLYING GROOVES WAS CHANGED TO A SPUTTERING OPERATION UNDER HIGH VACUUM USING ARGONION IMPACT TO REMOVE THE MATERIAL. THE RESULTING CHANGE IN YIELD OF WHEELS WAS INCREASED FROM ABOUT 10 PERCENT TO SUBSTANTIALLY 100 PERCENT DUE TO THE GROOVING PROCESS.

ORLANDO-HONEYWELL: In the proper operation of gas bearings, of course we need certain textures, grooves. spiral grooves on the thrust plates and on the channel (?) to operate properly. The problem here was that we would build, well these happened to be Polaris gyros, made of solid aluminum oxide. And in the course of testing and actually building the gyros, a very large number of failures occurred and it was unknown what was causing it. So a very detailed miscroscope study was initiated by a particular engineer, because this took a great deal of patience and he noticed that in the grit blasted area, and this was done by grit blasting. There are several methods of putting the grooves in. Certainly one of the least expensive and a very effective method of doing this is to grit blast the surfaces through a mask. And he noticed that in the grit blasted area there were little white spots and very carefully observing where the white spots were and then operating the bearing and looking again, he noticed the white spots disappearing and other white spots were coming up. He then did some scanning electron miscroscope investigation and he found that these

rate. Again, not because viscosity controls bleed rate.

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white spots actually were little cracks in the surface of the gas bearing. And this meant, of course, that the material while it was adhering to the base material, as the bearing operated, these cracks caused the material to leave the surface, and this in turn generated other spots and over a period of time this cascaded and the bearing failed. Now this is solid ceramic, solid aluminum oxide. So the lesson learned was that we couldn't use that process in this material and we went to sputtering. Sputtering with iron, argonion in an iron chamber. And this has given us -- completely eliminated the problem, that particular problem completely disappeared and the yield has shot up dramatically and this is the method that we are now using and are using in solid ceramic.

Now, I do have to mention that this action, which by the way has occurred in my experience on at least two separate and distinct companies as well as occasions, is not so prevelant in flame sprayed materials. In other words, all materials don't do it. The characteristic you have to have is where you can actually abrade the material in such a way that the particles still adhere either because they're encapsulated, they're loose, but they're encapsulated, or else the cracking is not complete at the time the abrasive blasting is done. I have some

Notice how small that quantity is. When you have numbers



slides showing the SEM's that I talked about, the photograph, I also happen to have some sputtered grooved parts. If anyone is interest in them. The sputtered grooving is a very beautiful groove compared to grip blasting although I don't think the gas bearing cares too much about it, but from the standpoint of asthetics, it looks pretty. I have some and if anyone is interested after the meeting I'd be glad to show it to them.

MILLARD-BAC: Any questions?

WONG-SINGER: One of the things you mentioned is that you don't think the gas bearing cares what the bottom of the grooves look like, I guess I differ with you from the point of view of cleanliness. On an SSY or grit blasting type configuration we find it very difficlt to clean that type of surface as opposed to a sputtering type technique. It's much easier to clean a sputtering surface and get a cleaner bearing than the grit blasting type procedure.

ORLANDO-HONEYWELL: It's certainly true that if you have dirt in the bearing for any reason that's bad, but if you assume that they are equally clean, I think that then it is not too critical. There is a couple of bad things, of course, about sputtering also. The edges of the grooves are extremely sharp, so you have to be very careful you don't knock those off in

the course of operating the bearing and the other thing, of course, with sputtering, you can overheat the parts and they can crack. So it's like everything else, you can do it wrong. But if you do it right, grit blasting on certain materials work very well, but sputtering, is something we are on agreement with there. Almost all our work is done by sputtering if it's a non-conductor. If it's a conductor, we almost invariably electropolish the grooves. And of course the last method, which hasn't been mentioned, I'll just mention quickly. Lapping the groove. That works very effectively, but it's usually a little complicated. United Shoe would probably do it that way.

MILLARD-BAC: Okay, I think I'd better hand this over to Bob now and you know you got about 15 minutes.

SCHIESSER-CSDL: I'll make up one real quick here. We have added this one in from our experience at the Draper Lab to go along with Vin just said.

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TOPIC: REMOVAL OF FRANGIBLE MATERIAL FROM GAS BEARING SURFACES.

DISCUSSION: AFTER FINAL FABRICATION OF GAS BEARING SURFACES THERE IS CONCERN FOR RETAINED LOOSELY BONDED SURFACE MATERIAL THAT IS SUBJECT TO PULL OUT REDUCING THE RELIABILITY OF THE GAS BEARING.

LESSON LEARNED: BY RUBBING THE BEARING SURFACE WITH 30-120 ALUMINA LAPPING COMPOUND ON A FELT TIP SPINDLE THE FRANGIBLE MATERIAL IS REMOVED IMPROVING BEARING LIFE.

SCHIESSER-CSDL: This has to do with the rest of the surface. And we find in the processing from prior lapping or however the coating was made, there may be areas that are ready to fall out, we found that a light polishing, lapping with a, in this case this 30-120 alumina refers to both the chrome oxide and aluminum oxide. We found that a very light polishing lap was helpful in removing possible problems that would occur downstream. Any questions on that.

ORLANDO-HONEYWELL: Another effective method we have found is to soda blast the surface after it's grit blasted.

SCHIESSER-CSDL: The next one was submitted by Lockheed and they didn't send any representatives, but I thought the subject was worth bringing up and Al Freeman is somewhat acquainted with the problem that Lockheed had so I asked him to cover it for us.

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TOPIC: GAS BEARING GYRO RAMPING START VOLTAGE

DISCUSSION: DURING EARLY PRODUCTION OF A TYPE OF GAS BEARING GYRO, A SERIES OF START PROBLEMS OCCURRED. SOME GYROS COULD NOT BE STARTED, SOME EVEN UNDER SATURATED CONDITIONS. TESTING OF THE MINIMUM START VOLTAGE, REVEALED THAT THE START VOLTAGES WERE INCREASING WITH TIME.

LESSONS LEARNED: THESE GYROS UTILIZED A CERAMIC BEARING MATERIAL AND IT WAS BELIEVED THAT ELECTRO-STATIC CHARGES WERE ATTRACTING CONTAMINANTS, MOSTLY

SMALL PARTICLES OF EPOXY DUST, TO THE BEARING GAPS.

AN IMPROVEMENT PROGRAM WAS UNDERTAKEN TO REDUCE THE AMOUNT OF EPOXY USED, TO IMPROVE THE PROCEDURE FOR CLEANING AND OUTGASSING, TO INCREASE THE MOTOR TORQUE AND TO CHANGE THE BEARING MATERIAL TO AN ELECTRICALLY CONDUCTED METAL MATRIX MATERIAL (FERRO-TIC).

THE RAMPING START VOLTAGE PROBLEM HAS BEEN ELIMINATED BY THESE CHANGES.

AL FREEMAN-CSDL: In this particular case, it was a gyro program that Lockheed was interested in and there was a program being conducted by a gyro manufacturer. The bearings were ceramic and they observed a gradually increasing start voltage as the bearings were operated. Eventually they traced this problem to an electrostatic charge build up each time the bearings were started and stopped and they also detected the collection of material, foreign material in the gap and the speculation was this foreign material was epoxy, and also a certain amount of the ceramic that had come loose.

The way they solved the particular problem was to change from the ceramic to a ferro-tic which is an electrically-conduct~~ed~~ive material and that particular problem went away.

On another case, not this particular one, we have seen that the use of the same ceramic, if it is lubricated does not result in this static charge build-up. Any questions?

JACOBSON-S-FS: Are these static charges induced by the normal operation of the bearing after (?)

FREEMAN-CSDL: No, the static charge is built up only during the starting and stopping, not during the operation of the bearing.

SCHIESSER-CSDL: This one comes to us from the British Aircraft Corporation and I'll let Colin Millard take it.

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TOPIC: GAS BEARING GYRO FLOAT FAILURE PATTERN

DISCUSSION: A SERIES OF GAS BEARING GYRO FLOATS WAS TESTED, WITH TEMPERATURE CONTROLLED BY HEATER BLANKETS. THE HEATERS CYCLED REGULARLY WITH THE WHEELS OFF, INTERMITTENTLY DURING STOP-START TESTING, AND REMAINED OFF DURING CONTINUOUS WHEEL RUNNING. RESULTANT FLOAT TEMPERATURE WAS AS HIGH AS 172°F. MINIMUM START VOLTAGE INCREASED RAPIDLY FOLLOWING CONTINUOUS RUNNING, INDICATING BEARING FAILURE.

LESSONS LEARNED: CONTINUOUS OPERATION OF THE LUBRICATED GAS BEARING SIGNIFICANTLY HOTTER THAN NORMAL CAN CAUSE EARLY FAILURE.

MILLARD-BAC: I must admit I'm thrown before I even start because it talks about degrees F.

Really, I think all this is really trying to say is that all of your testing at all stages should be as closely as possible aligned to the service conditions. We run our particular gyros actually in fleet service on an overvolted running condition so that the power input to the (?) wheel is very, very much reduced.

For many years we have run the floats during their testing on a perfectly ordinary 400 cycle three phase supply. This was for convenience, low cost test gear as much as anything else. We then slightly modified the heating system of the floats, an external heater mat system. We improved the thermal insulation of the system because we thought, well, if you get a better thermal stability, you're going to get better running conditions. And we noticed quite a considerable degradation in performance.

And it turned out in fact to be that we had insulated the system too well, because we were putting more power into the system, the running temperature of the wheel was increasing quite considerably, 8 to 10° C probably. In fact, affecting the bearing condition.

What we did was, as I just said, look at how it's running in fleet service, change our testing supply to another voltage supply and the problem went away.

DENHARD-DRAPER: Was this associated with lubricant migration and you could clean the bearing and relubricate and recover?

MILLARD-BAC: In general, we could relubricate and recover. Obviously it's very expensive and very time-consuming. I have a piece here from Brian Baxter, who many of you will know. If I can take about two

minutes out to read it. I'm not certain whether it will answer your question -- I'm not certain I even understand it. It says here it has been known for some time that the gas-bearing wheel generates a secondary lubricant consisting of metal oxide, primarily iron, wear debris, and this is seen as thin film deposits after running. This debris having a particle size of colloidal dimensions carries strongly absorbed polar material -- including the formal wheel lubricant -- on its surface. Laboratory experiments have shown clearly that fatty acids are chemisorbed to the surface of certain iron oxides and the resulting surface compound has been characterized by IR spectroscopy.

Just prior to the modification of the continuous run conditions, the bearing surface deposits appeared different from normal in that they were associated with thin films of crystalline material, in contrast to the usual amorphous wear debris.

The possibility must be considered that the colloidal wear debris, stabilized by chemisorbed fatty acid is unstable above a certain temperature -- so at last we get to the temperature bit. Thermally induced effects could include either the formation of a distinct iron III melissate phase, or the complete disruption of the system into iron III oxide and full melissic acid, which is our

formal lubricant.

Analytical proof of the above changes is difficult to obtain and our results are not clear enough to make a firm diagnosis owing to the very limited sample sizes involved. There's a typical service chemist let-out there.

However, reduction in the running temperature of the system has prevented the recurrence of the bearing effects described, and thus providing some circumstantial evidence in support of the hypothesis.

ORLANDO-HONEYWELL: First, there are many, well, there are gas bearings that operate continuously I believe at 185°F. These surfaces that I know of are aluminum oxide. If you run these wheels continuously and the lubricant hasn't been properly set up, you don't get the chemical bonding. At the end of the continuous running period, you'll find static voltage will go up significantly. If you temperature-cycle the wheel, the wheel will return to normal. I take from what you have said and what Brian said that you were talking about metal bearing surfaces. In the case of ceramics, I don't believe that occurs.

MILLARD-BAC: Yes, we have noticed the same sort of effect on ceramic surfaces. All I can say is that metal surfaces seem particularly prone to temperature

and again echoing what was said yesterday, if you are going to run a system, then it should be run in the proper conditions and this is really being thrown off on this particular exercise that if you run anything outside those conditions, you're heading for trouble.

SCHIESSER-CSLD: Another interesting input comes to us from Bendix, and it was submitted by Howey Julian,and Howey couldn't make it to the meeting and I'm familiar with the problem so I'd like to address it for him.

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TOPIC: STATIC CHARGE PROBLEM WITH CEMENT ON 64 RIG WHEEL.

DISCUSSION: ADHESIVE WAS DEPOSITED ON WHEEL BEARINGS SURFACES VIA ATTRACTION TO HIGHLY STATIC CHARGED "CERAMIC" SURFACES WHICH LED TO START VOLTAGE DEGREDATION AT HIGHER ASSEMBLY LEVELS. SUBSEQUENT INVESTIGATIONS PROVED LOCAL DISCHARGE OF PARTS TO BE INADEQUATE BECAUSE THE CONTINUOUS DRY AIR FLOW OF THE CLEAN STATIONS RAPIDLY REBUILDS THE CHARGE ON THE "CERAMIC" MATERIALS.

LESSONS LEARNED: THE RESIDUAL ON CERAMIC MATERIALS CAN BE KEPT NEAR ZERO IF THE FILTERED AIR PASSING OVER THE PARTS IS CONTINUOUSLY IONIZED.

THIS HAS BEEN ACCOMPLISHED FOR THE 64 RIG WHEEL BY UTILIZING THE RADIOACTIVE STRIPS ALREADY IN USE, BUT IN A SLIGHTLY DIFFERENT MANNER. INSTEAD OF TEMPORARILY DISCHARGING THE PIECE AND ALLOWING IT TO BUILD UP CHARGE AGAIN, A LOW RESIDUAL CHARGE IS MAINTAINED THROUGH CONTINUOUS IONIZATION OF THE FILTERED AIR IN THE LAMINAR HOOD BY PASSING

IT OVER THE STRIPS. ALPHA EMISSION FROM THE STRIPS IONIZES THE AIR WHICH IN CONTACT WITH THE PART, NEUTRALIZES ANY POSITIVE OR NEGATIVE STATIC CHARGE PRESENT.

SCHIESSER-CSDL: This was a static charge problem. The source of the static charge could have been from prior operations or from as Al mention in another company's experience -- the running and starting and stopping of the wheel.

After they sealed -- or as they were sealing the wheel into the float assembly, there are some plugs near that go around the middle of the float assembly that are near the wheel. These are balancing mechanisms that are cemented into the float structure and also make the seal to the outside.

They found that as they were putting the adhesive onto the seals, the adhesive would -- a capillary action run in and make the joint -- but in addition to that, because there was a static charge on the wheel, the adhesive was actually jumping over onto the wheel and their solution to that problem was to introduce the use or to increase the use, I should say, of ionization elements in the assembly area to reduce the static charge on the assembly as it was being built. Any questions?

MILLARD-BAC: All I can say is it was well worth coming here because I just learned one hell of

a lesson.

SCHIESSER-CSDL: The pictures they had were very interesting. They had stalagmites or stalactites -- I don't know which way is up. Well, yeah. Actually they did it, the unit was OA up so what's for horizontal?

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<u>TOPIC:</u> FLATNESS OF THRUST SURFACES

<u>DISCUSSION:</u> SLEW RATE CAPACITY IS DEGRADED IF AXIAL GAP OF SPOOL BEARING IS CLOSED.

<u>LESSONS LEARNED:</u> IN COMPOSITE SURFACES, i.e., SPRAYED CERAMIC ON BERYLLIUM, WARPAGE WAS NOT CONSTANT FROM LOT TO LOT. IT BECAME NECESSARY TO ESTABLISH THRUST PLATE FLATNESS AT OPERATING TEMPERATURE.

FROMM-DELCO: This seems sort of obvious, you should have flat thrust plates, right?

What happens if you don't. We found the slew capacity of our gyros suddenly degraded. And this is a fairly recent problem. We've been in the business of making this machine for close to ten years. Within the last year we suddenly ran into a spell where we couldn't pass our in-house slew capacity requirement.

And we went through the usual sort of a witch-hunt, perhaps not starting with the obvious. We looked at groove depth, groove configurations, groove to land ratio on the thrust plates, looked at the general geometry. Slewing capacity is not well described analytically. The analysts don't deal with geometric

imperfection and the imperfections in a gas bearing are on the order of, what, 20 percent of the running gap? They are important. They don't deal with porosity and the like. So you don't really know when you get into a performance difficulty of this kind where to go too precisely from analytical data.

We found no change in processing, the geometry was all the same as it had been for years. Almost by accident we stumbled on the fact that the thrust plates which have a coating of plasma sprayed alumina on beryllium and fairly thick, about 3 percent of the total thickness of the thrust plate is alumina. We found that they were warping where they had not before. And they were therefore constricting the axial gap. The stiffness was essentially as it had been, but there wasn't the room for the rotor to go through its angular excursion; therefore, it could not meet our spec.

We never were able to trace what had caused the warpage that we hadn't seen in the past, but we addressed it then by assuring that the plates were flat at the operating temperature, which is about 170°.

SCHIESSER-CSDL: We're about ready to stop for a break and we're darn near on schedule so I'd like

to add these announcements. That any technical inputs that you may have after this session, they will be accepted. They should be forwarded to Jerry Blaine and they will appear in the next newsletter. I guess if later than that, they would appear in the following newsletter. Coffee is about now in the Green Room.

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SCHIESSER-CSDL: We had a couple of questions during the break and Al volunteered to answer a question that was raised before on performance of the G200 bearing in the plate.

MOZELL-NARF: I'm in quality engineering analysis there at NARF and since the implememtation of the polyimide retainer bearing there at NARF, we've experienced significant increase in reliability both within the NARF and also in the squadrons from Oclana Naval Air Station which is located nearby, as well as the ANS42 community on the P-3A.

November 1976 to March 1977, we built up 217 total wheels at which we had a success rate of 96.77, which gave us only a 3.23 reject rate. We did have a few mass shift problems with some expoxy and so forth, but overall the polyimide retainer bearings are working pretty well for us. We have

occasional problems that come up in the clean rooms, cleanliness and so forth, but overall it's working pretty good for the Navy on the East Coast. Any questions?

SCHIESSER-CSDL: There was a question directed towards Herb's presentation on surface contamination.

FREEMAN-DRAPER: Unfortunately, the questioning on the discussion of surface chemistry was cut off kind of short and there are a couple of other points that should be mentioned. One is that in the time alloted, Herb didn't really have time to go into the shades of grey of surface chemistry and presented a relatively black and white picture. Now, there are shades of grey as has been seen by Ed Kingsbry at Draper Lab and also by Pat Boyer at British Aircraft Corporation. Some of you may remember that at the bearings workshop last year, Pat Boyer made the comment that the surface chemistry as cited by Draper Lab has not been fully -- he has not been fully in agreement with all of the work that he had seen here. And Pat has pointed out that bearings that are not wettable can be made to run successfully, for example. And it is a fairly complex subject and we have seen evidence that wettability is not in every case a requirement, though it has been a good method of control and one

that permits you to evaluate the bearing as a starter.

Now, Herb may have other comments on that, but I wanted to let Pat Boyer's views at least come to the fore on the subject.

Now, there was another area of surface chemistry that has not been discussed, which we think is quite important and John McHale has volunteered to speak to that particular subject.

McHALE-NAVY: The fellow that really found the problem was Harold Ravner of the Naval Research Lab. The problem is relative to the packaging material, the nylon and the polyethelene bags that bearings are typically packaged in. Both of these materials have an anti-static additive and the anti-static additive has been found to leach out of the bearings -- excuse me -- out of the packaging material and effectively go through the lubricant as a conductor and coat the metal surface of the bearing just like a barrier film would.

Now, the additive leaches out of the nylon about 1/10th of the rate of the polyethelene. So the Navy has adopted in all of its rework facilities a rule that we are not going to use polyethelene packaging material until we get a better additive, and anti-static

additive and I am getting funding into NRL to develop a better additive.

The real long-term problem is that the nylon -- the solution is we're right now using the nylon with the additive, but that's a short-term solution. The long-term solution, we must go back to the polyethelene with a better additive because the nylon does allow vapor to process through it into the bearing and cause another problem of corrosion.

Now what we are saying, in the material, the material, whether made of the plastic or the nylon is about the same, so the effective cost of the packaging material is the same. But I don't think we are really going to be able to change the ways of the manufacturer of the material right now because we are only using maybe 2 or 3% of his total production. Most of the material is used for the electronics industry. I have been trying to drum up some interest in industry to determine if indeed the same additive is not one of the sources of the solderability problem we are finding in the microelectronics industry. It may be one of the main causes of it. Because it can leach out onto the ends of a component just like it leaches out onto the metal of a bearing, it could care less.

For particular details of all that, I would urge you to get in touch with Harold Ravner at Naval Research Lab.

FREEMAN-DRAPER: Let me get one final phrase in on this issue. That is that I think more and more we are seeing the significance of surface chemistry in a lot of areas that it hadn't been considered in before. We have been talking about it for gas and ball bearings, John just mentioned it in microelectronics and also of course in slip rings it's a very significant issue and I think as we look into it, we are going to find it to be more and more important in quite a number of areas.

DARRIS-SPERRY: I'd like to suggest double-bagging in that last bearing application; use a nylon bag inside and polyethelene outside to prevent corrosion.

McHALE-NAVY: That's still not going to solve the problem ultimately, because nylon, the material, the anti-static material in the nylon still leaches.

SCHIESSER-CSDL: I put this on and this has been in general, this topic has been presented before at these meetings.

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TOPIC: THE SCREENING OF GAS BEARING FOR RELIABILITY CAN BE IMPROVED BY USE OF DEMAGNETIZED RUNDOWN ANALYSES.

DISCUSSION: THE LOW SPEED OF A GAS BEARING TEARDOWN IS VERY SENSITIVE TO THE MECHANICAL IRRGULARITIES OF A GAS BEARING AND THE DATA CAN BE EVALUATED FOR CONTAMINATION.

LESSONS LEARNED: BY ADEQUATELY DEMAGNETIZING THE SPIN MOTOR TO MAKE ITS BACK EMF INSIGNIFICANT, ADEQUATELY CHARACTERIZING THE LOW SPEED END OF THE CONTACT (LANDING) PERIOD WILL INDICATE CONTAMINATION LEVELS, OR OTHER PROBLEMS OF SURFACE CONDITION.

SCHIESSER-CSDL: We have been working at the Draper Lab for over four years now on this demagnetized rundown analysis and I use the word analysis because it isn't a single data point, it is looking at a number of data points. The object is to characterize the low end of the touchdown curve on a gas bearing to see if the wheel is landing in a wheatfield or a marshfield or a sheet of ice. And we do get very good data regarding the quality of the gas bearing, surfaces, you can characterize the family, you can find out if you have contamination in the bearing, you can also find out if you built the bearing in a geometric sense incorrectly.

We recently had a wheel that had very high touchdown speeds but was very repeatable, and it seemed to us that that was characteristic of a cock thrust plate and we took the bearing apart and well, it was a cock

thrust plate, due to the fact that the shaft was bent with the installation.

So you can pick up not only cleanliness problems, processing problems, surface chemistry problems, particular problems, but you can also pick up stress assembly, improper assembly from a geometry standpoint. Any questions?

I guess I'll turn this over now again to Colin.

MILLARD-BAC: Thank you, Bob. This is one where I start right back in again.

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TOPIC: MAGNETIC MOTOR EFFECTS ON ROTOR BALANCE

DISCUSSION: THE OVERALL STATE OF DYNAMIC BALANCE OF THE GYROSCOPE ROTOR IS AFFECTED BY THE APPLIED STATOR VOLTAGE. ANY UNBALANCE EFFECT IS CHANGED, BUT NOT REMOVED WHEN THE SUPPLY IS SWITCHED OFF.

LESSONS LEARNED: MAGNETIC ROTOR FORCES CAN BE HIGH ENOUGH TO SIGNIFICANTLY RAISE THE SPEED AT WHICH THE GAS BEARING WILL CONTACT DURING RUNDOWN.

MILLARD-BAC: We've been looking at instrumentation of gas bearings for the last year or 18 months, particularly on the torque measurements on touchdown and takeoff.

One of the things which has really come out of this, perhaps this is fairly common knowledge, I don't know, the balance condition of the wheel is very much

decided by the power supply that you use, whether you are overvolted, whether you are undervolted, whether you are running normally.

Perhaps what hasn't been realized up until now, this goes straight into the (?) on the gas bearing itself. Touchdown speed is very, very much affected by the balanced condition of the wheel and in fact the speed at first touch on rundown can go up by maybe a factor of 2 with a three-fold increase in the time of sliding taking place in the last few revs of the wheel.

Really, I think the wear rate must increase as a result of this. Where it comes down to roost, again it comes back to what I was saying earlier, we've not really in the past taken very much notice of this sort of thing. We've been doing initial balances of the wheel assembly under ordinary 400 hurtz rough supply conditions and we are getting one balance condition and we are fairly happy with it. You put it into service and it's running under a slightly different supply condition, the balance condition changes, the touchdown speed changes, the sliding time distance changes. This may well be one of the reasons why there doesn't seem to be much correlation between having a good wheel in the factory and maybe having a good wheel

in the fleet. Okay?

JACOBSON-SPERRY: Did you find any relationship between whether or not your overvoltage of the motor is starting with this effect?

MILLARD-BAC: We've not actually looked at that. We only do overvolting during continuous running. Although, I'm just thinking back to some of the results and I think there is very likely to be an effect there. It would appear that these results -- these results have really only come to life in the last few weeks -- and it would appear that the overvoltage condition is the worst condition you can run in, as far as imbalance is concerned.

FROMM-DELCO: What do you think is happening to change the contact speed? Is the bearing itself distorting or is it a (?) EMF that's changing or the magnetic gap that's changing and changing the viscous drag there?

MILLARD-BAC: I think it's the magnetic gap that's changing.

I'm going to call on Sam Wong of Singer-Kearfott.

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<u>TOPIC:</u> ASSURING BEARING CLEANLINESS

<u>DISCUSSION:</u> GYRO YIELD HAS BEEN FOUND TO BE VERY SENSITIVE TO CONTAMINATION (ORGANIC

OR PARTICULATE) FROM POOR PROCESS INSPECTION CONTROLS, CLEANLINESS OR CONSUMABLES, EQUIPMENT, ENVIRONMENT, AND CONTAMINATED FIXTURING DURING PROLONGED MOTOR RUN-IN.

LESSONS LEARNED: ADEQUATE YIELD ABSOLUTELY DEMANDS CONSTANT SURVEILLANCE AND RELENTLESS MONITORING OF WHEEL AND GYRO ASSEMBLY AREAS, INCLUDING NOT ONLY BEARING AND WHEEL HARDWARE, BUT ALSO ALL ASSOCIATED TOOLS AND EQUIPMENT. PERSONNEL DISCIPLINE THROUGHOUT THE COMPLETE BUILD PROCESS IS ALSO VITAL.

WONG-S-KF: One of the things in the bearing industry we find that over the years we're finding out that the problem of controlling cleanliness. We've done a lot to improve wettability, getting very clean bearings, running wheels in, taking them apart, examining them for lube conditions, retainer condition, tracking; then we put it back together again, we shift the wheel and we find out that later on the controls that we used to build the wheel, we really don't use afterwards. We tend to, ourselves, relax some of these controls. The feeling is that once you've lubricated the bearing, gee, they're clean, they're good, and on a high assembly area you find out that there is a tremendous tendency to back off on a lot of controls on some of the solvents, some of the cementing procedures and the cleaning procedures.

So it's back again to process controls. Controls in a high assembly area, where in this case it really is a production problem, you have to maintain

that quality all the way through the motor build. You can't stop at the build phase, and say we've cleaned the bearings, we've got a very good set of bearings and that's the end of your problems. We're finding out more and more that there's a lot of equipment on subsequent operations, cementing procedures, dynamic balancing procedures that have to be very closely monitored, not only during build phases, but at the later stages.

We seem to relearn this lesson over and over again. And once you develop a very good line with a very high yield, there's always a tendency, because of cost reasons, to back off,to try to eliminate some of the controls. And invariably you always run into trouble. And one of the things we learn is that you must maintain constant surveillance of the line from the beginning of the line all the way up to the final sealing of the unit. If you don't, you can really get burned. You get burned by equipment and everything else.

DENHARD-DRAPER: Sam, I'd like to ask you, how long do you think it takes to have someone working on the line to learn and understand the problem and

comprehend what clean is?

WONG-S-KF: I know your question very well, Bill. Part of the training, I would think that an individual that's been in the bearing business, it takes many years. And to really understand the degree of cleanliness required, it's not something you can train someone three months, four months, and put them on the line and say you're an expert at cleaning bearings and handling bearings.

Part of the problem is that it's a learning process. A lot of things can screw up a bearing. There's so many things if you go through every detailed process. I think it takes years to develop this knowledge and experience.

MILLARD-BAC: I think the answer really to your question is there is no time limit; we never learn. Sam has just said time and time again we run into the same problem. So you can train a guy, you can control him, but ultimately we never learn the lesson.

DENHARD-DRAPER: Then I would assume that a practice which says that you promote someone to a different line of activity after a few months would mean that you always have untrained personnel in the bearing area. If you promote people in the bearing

area after a few months because they've matured in that and are therefore capable of earning higher pay through a different activity then I would think you would never have trained people in the bearing area.

MILLARD-BAC: I think I would have to say that in inertial navigation system, you have to throw the management rulebook out the window. You've got to keep the trained people there continually and that's probably where the money management problem comes in, is keeping the guy motivated year in and year out, because as Sam says, you're going to get burned if you get rid of him.

GARDOS: Have you considered money?

MILLARD-BAC: I come from the UK. I consider money.

WONG-S-KF: The cost involved on a low level, and there is significant high cost in trying to control the solvents, the polishing compounds, all the processes, but think of one platform failure, if you have to tear it down because of a wheel or system failure and take those dollars involved in the build-up and tear-down and you find out over the years that every so often you get into a big task force on bearings and you spend hundreds of thousands of dollars and amortize that over the 10 or 15 years, and it pays off.

So I think you have to spend the time, you have to spend the money on that level. It's just you can't back off; otherwise, you're going to get into trouble.

SINGER-DRAPER: I agree with the conversation that was going on about constant surveillance in the bearing area and I would bring up the point also on procuring bearings, the specifications and the cost of that bearing. If you pay $2.00 for a bearing and hope to get many, many years for a bearing, you are asking for trouble. You have to specify and obtain a good quality bearing for long life high performance and you have to pay the money for it.

WONG-S-KF: One thing I think with the cost, one of the things that we had to implement as a control was the wet test I was just discussing. Surface chemistry. We feel very strong about that. That's one of the early screen tests for determining a good bearing. We also determined that we run the motors in 150 hours, we'll take it apart and visually examine it. We have a complete spec on acceptance criterias for tracking, for wetting, for (?) for retaining condition. Then we'll put it back together again. That's our only safeguard that those two operations that we can really tell whether we have a potential problem. And if you do that, the chances are nine out of ten

you will eliminate the lube breakdown problem that may occur. To my knowledge, there'sno real tool I can tell you to spot a lube breakdown. It's only a visual examination. They're trying to make tools for that, but it's not available. Visual observations tell you an awful lot.

MILLARD-BAC: Dale McLeod of Autonetics.

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TOPIC: LOW TORQUE BEARINGS.

DISCUSSION: LOW TORQUE AND SMOOTH OPERATION ARE ALWAYS DESIRABLE AND FREQUENTLY THEY ARE PRIMARY DESIGN REQUIREMENTS FOR BALL BEARINGS. BEARING MANUFACTURERS GENERALLY AGREE THAT 52100 STEEL CAN BE MADE SLIGHTLY HARDER AND MACHINED SLIGHTLY SMOOTHER AND ROUNDER THAN 400C. THIS SUGGESTS THAT 52100 WOULD BE DESIRABLE WHERE LOW TORQUE IS NECESSARY. FOR SMOOTH OPERATION, HOWEVER, CLEANLINESS IS ESSENTIAL. DUE TO ITS TENDENCY TO RUST, 52100 CANNOT BE CLEANED AS THOROUGHLY AS 440C, THUS THE SLIGHT BENEFIT OF SMOOTH SURFACE FINISH IS LOST AND RUST PITS CAN EVEN PRODUCE A ROUGHER SURFACE. OIL ON EXTERIOR SURFACES IS NOT ONLY A DIRT CATCHER BUT PRODUCE HANDLING PROBLEMS WHICH MIGHT RESULT IN IMPROPER HANDLING AND DAMAGE TO THE BEARING.

LESSON LEARNED: AUTONETICS HAS ESTABLISHED A GENERAL POLICY THAT UNLESS THERE IS GOOD REASON TO USE 52100, ALL BEARINGS ARE TO BE MADE OF 440C CORROSION-RESISTING STEEL. ONE EXCEPTION MIGHT BE WHERE TEMPERATURE CONDITIONS REQUIRE THE USE OF 52100 BECAUSE ITS THERMAL EXPANSION RATE IS CLOSE TO SHAFT OR HOUSING MATERIALS.

McLEOD-AUTONETICS: This is a fairly simply chart. It just describes the judgment that we've begun to apply to our bearing applications.

Particular point which has occurred to us several times is with regard to the handling that is required for the 52100 material described in the last sentence down there.

Recently we had an application using the 52100 where we were having some problems and we sent a batch of bearings back to the manufacturer to get very good cleaning, clean all the oil and contamination and everything and package them very carefully and send them back to our bearing lab where we could run tests and lubricate them ourselves. Well, they did this all according to instructions, but they had a very experienced technician there and he was packaging the bearings to send them back to us. Being a very good technician, he says, you know 52100 rusts, so I'll put some oil on them. So he put oil on all the bearings and shipped them back to us, which just cancelled out all we wanted to do.

So we have established general policy of using the 440C material unless there are special considerations such as the temperature coefficient of expansion that requires it.

MILLARD-BAC: Thank you. Back to Herb again of CSDL.

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TOPIC: PASSIVATION OF LOW SPEED BEARINGS

DISCUSSION: AN INSTRUMENT THAT INCORPORATES A PAIR OF OSCILLATING BEARINGS HAS BEEN IN PRODUCTION FOR A FEW MONTHS WITH NO FAILURES UNTIL A NEW LOT OF BEARINGS WAS INTRODUCED. THESE BEARINGS FAILED IN LESS THAN 5 HOURS OF OPERATION. THE FAILURE WAS CHARACTERIZED BY ERRATIC TORQUE CAUSED BY THE METAL BEING TURN DURING OPERATION.

LESSONS LEARNED: THE RACES AND BALLS OF THESE BEARINGS WERE MADE OF 440C STAINLESS STEEL AND WERE TO BE PASSIVATED. IT WAS FOUND THAT THE BAD LOT OF BEARINGS WERE INDEED PASSIVATED BUT THE RACES WERE RELAPPED AND NOT REPASSIVATED. PASSIVATING THE UNUSED BEARINGS OF THIS LOT ELIMINATED THE PROBLEM.

SINGER-DRAPER: This is another interesting lessons learned.

We found some years ago that TCP treatment, which maybe we'll get to later on, and passivation of 440C will allow bearings to run in the very critical area of boundary lubrication, oscillating at a very low speed.Untreated bearings will fail in a short period of time.

Someone called up and they had an application in which 440C bearings were running in an oscillating mode and they were having great success until they got one lot in which after a few minutes of running in an oscillating mode the bearings would fail. Metal particles would be torn out of the races, reddish-brown deposits. What to do? Were the bearings passivated? Yes, they were passivated. Maybe TCP treatment is needed also

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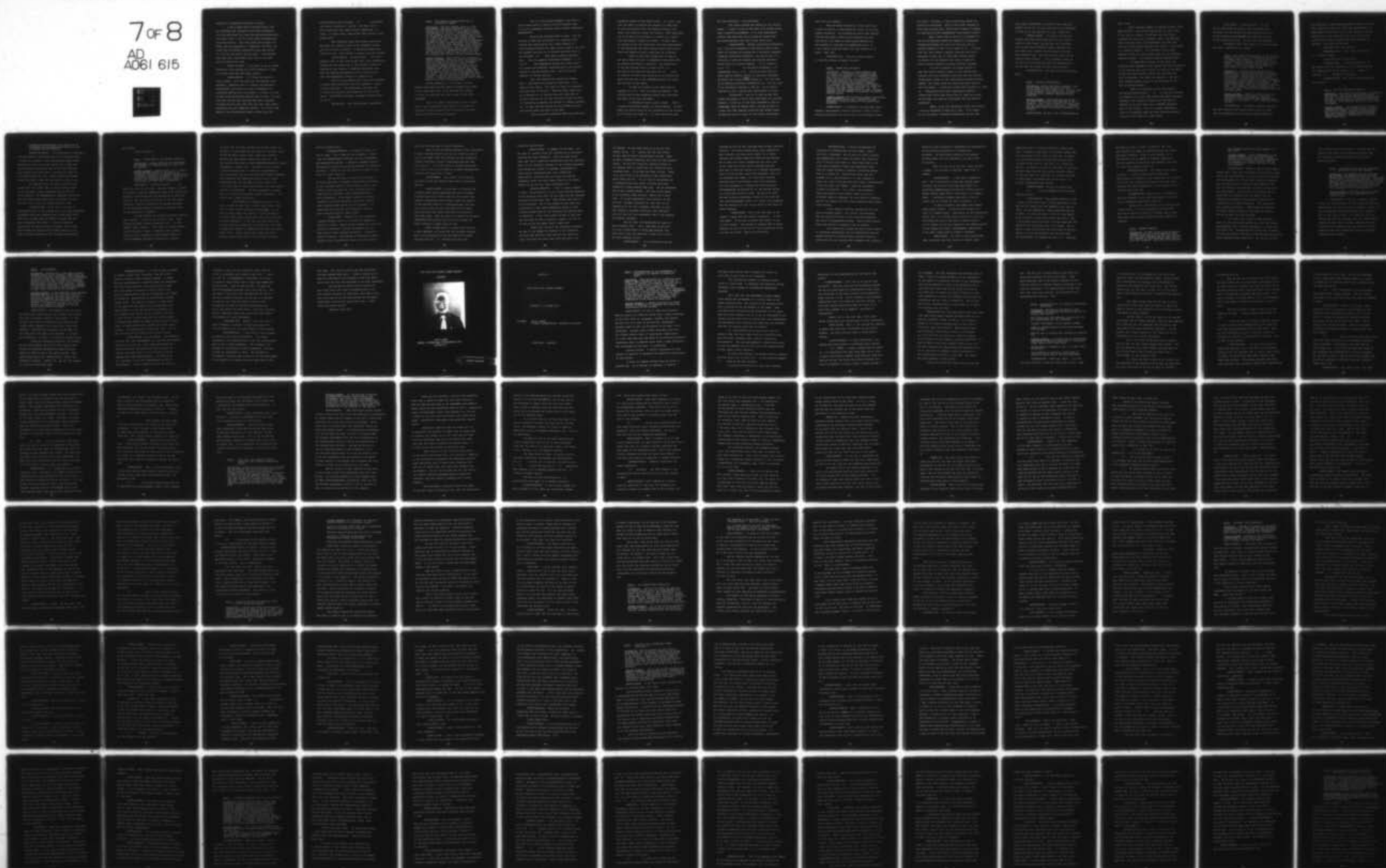

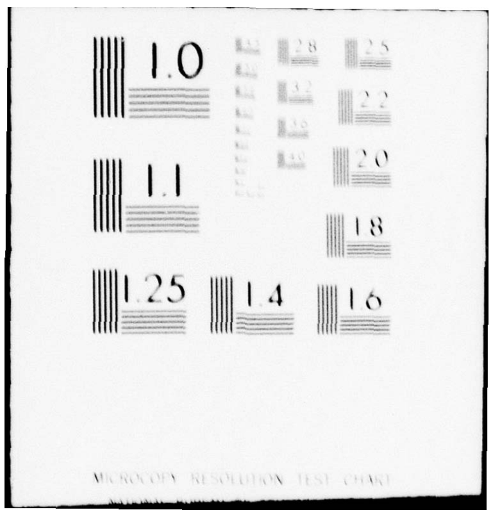
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MICROCOPY RESOLUTION TEST CHART

because of a suspended belt-type of thing.

I got a phone call a few days later, that the bearings were supposed to have been passivated, but this particular lot, when the bearing manufacturer -- not anyone here -- saw the races before packaging and they were defects. They went ahead and relapped the races, did not repassivate. Therefore, the film, the oxide film or whatever passivation does that allows it to run at low speed, was not there. The bearings were sent back, passivated, sent back to the user, and the problem went away.

Lesson learned: if you want to put a surface protection like passivation or TCP treatment, it has to be done after the last metal removal.

GARDOS-HUGHES: It's funny how we don't learn lessons. It's not just that the bearing technologists sometimes fails to consult the materials' technologist, but there is so much information in literature dealing with the subject. In fact, I'd like to quote from the British workers back in 1962, '63, and they were testing ball bearings that had to operate in helium and the very fact that the oxide layer wasn't reforming, they got immediate failure. So at that time smartly, they incorporated sodium nitrite into the

bearing grease which provided (?) passivation even during operation in helium. And that work in 1963 turned into the sodium nitrite containing (?) today. In other words, some people learn lessons, some people don't.

That indicates again that please take notes and above all, please consult your literature before you try to solve a problem. It may have already been solved for you. Your library is really your best friend.

SINGER-DRAPER: One more point. I've read recently that is that some groups don't like passivation; because you are going back to the original reason for passivation was because of removing trap metal from 440C and bearing manufacturers don't use 52100 and 440C interchangeably, there's no reason for it.

Here's a good example and I can quote hundreds of others that passivation and TCP treatment -- which is also effective -- but passivation does give you a film on the surface that allows you to run at low speed. Unpassivated bearings, untreated bearings will not do it.

MILLARD-BAC: Dale McLeod again, Autonetics.

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TOPIC: HIGH BEARING FAILURE RATES DUE TO ELECTRICAL CURRENT.

DISCUSSION: THE BALL BEARING USED AS A STOP FOR LIMITING GYRO ROTOR MOVEMENT ON THE F-11 AIRCRAFT G9 FREE-ROTOR GYRO IS A SMALL BEARING APPROXIMATELY R2 IN SIZE. INTERMITTENT CONTACT OF THE SPINNING ROTOR IS MADE AGAINST THE OD OF THE NORMALLY MOTIONLESS STOP BEARING DURING START-UP, COAST DOWN, AND PLATFORM SLEWING DURING CALIBRATION PERIODS. RAPID LUBRICATION BREAKDOWN AND WEAR OCCURRED ALTHOUGH NORMAL BALL BEARING TESTS ON FIXTURES WITH COMPARABLE LOADS INDICATED LONG-LIFE EXPECTATIONS. THE PROBLEM WAS FINALLY IDENTIFIED AS ELECTRICAL ARCING CAUSED BY 5KHZ PICKOFF VOLTAGE DIFFERENTIAL BETWEEN THE ROTOR GAS BEARING BALL SHAFT ON WHICH THE ID OF THE BALL BEARING WAS MOUNTED, AND THE SPINNING ROTOR.

LESSONS LEARNED: WHEN TESTING BALL BEARINGS TO ACTUAL OPERATING CONDITIONS SHOW GOOD RESULTS AND EARLY FAILURES STILL OCCUR ON THE INSTRUMENT, LOOK FOR POSSIBLE ELECTRICAL CAUSES. THE CAPACITANCE CREATED BETWEEN THE INPUT-VOLTAGE CARRYING SHAFT AND THE GAS BEARING BALL WAS ELIMINATED BY ADDING A CONDUCTIVE CEMENT PATH TO THE NORMALLY USED EPOXY CEMENT BETWEEN BALL AND SHAFT. INSULATION COATING BETWEEN THE STOP BEARING ID AND THE SHAFT WAS CONSIDERED BUT NOT ADOPTED. BEARING FAILURES HAVE BEEN SIGNIFICANTLY REDUCED AND EARLY WEAR ELIMINATED.

McLEOD-AUTONETICS: I'm filling in for my bearing lab people and was asked to present this chart. It is a very busy chart so to describe the problem I'll let you read that and then I have a very crude schematic.

This is a pretty interesting lessons learned here of the cooperation that needs to be between the electrical design engineers and the bearing engineers and the instrument design engineers.

This is a very crude schematic, but this is the G9 wheel which is used in the N-16 system, used in the F-111 aircraft and also used in attack submarines applications.

This is the rotating wheel up here. The gas bearing is here and the pickoff is a capacitor type pickoff here that detects any relative motion in this direction between the wheel and the case of the gyro. The pickoff then goes on to pickoff amplifiers and to the platform (?). They have a pickoff generator here. This is a greatly simplified schematic. 5 (?) 4.8 (?) The computation showed that there would be a three-volt potential developed due to the pickoff current in the gas bearing here. Just due to the capacity of the gas bearing.

Now, the bearing that caused the problem here -- developed the problem is right here. It's fixed to this shaft. The shaft of course is insulated from the case of the gyro. When the wheel slows down or is started up, it wobbles here and comes down on the stop bearing and the stop bearing is there to keep it from going up against the pickoff or tearing anything up. So that the stop bearing or ball bearing is only used during start and stop of the gyro.

The calculation showsthat there was three-volt

potential across the gas bearing here. Of course, that when the wheel is started and stopped, it comes down on the stop bearing here, the bearing rotates, that three volts would be across the bearing. That calculated out to be about 200 microamps of current for a short time and wouldn't cause any problem. In fact, when we started to get the rapid wear, very bad contamination of the bearing we ran tests putting three volts across there and indeed it didn't cause much of a problem.

Later it was found though that on many of the gryos where the ball is cemented to the shaft here, we actually developed a capacitor. The capacitance of the gas bearing itself is about 9,000 (?) and some of the gyros we had about 900 (?) here. So instead of three volts across here we actually had about 33 volts due to the impedence between the shaft and the ball in the epoxy.

So that the current is ten times what we computed it to be. That is indeed the problem. The solution was to use conducting eopoxy here and reduce the peaks in the ball and shaft.

In retrospect that's pretty simple. That's a pretty simplified schematic of the situation. It isn't nearly as obvious when you are searching for the problem as it is when you found it. I'm sure nobody else has

had that experience. Any questions?

The lesson learned was written by our bearing people. I guess I'd add to the rest of my design people that a simplified schematic of a very complicated circuit like this when you're doing the design work may avoid mistakes like this in the future also.

SINGER-DRAPER: Another interesting observation when I saw this viewgraph is that here we have a case where not running the bearing has a lubricant breakdown caused by electrical discharge. You can see why it's difficult to give the reasons why bearing lubricant breaks down on a running bearing. Is it oxidation, is it (?) it electrical discharge, is it temperature, you name it. But we do know that the first sign of bearing failure is lubricant breakdown. We really don't exactly know what causes it. You can cause it by putting electrical discharge on it. You can cause it by ultrasonic cleaning of the oil. In a running bearing you don't usually have these kinds of things.

MILLARD-BAC: Sort of to take up what Mike Gardos was saying a little while ago about not learning lessons, I think one of the major problems is that at technology level or design level, the way we work is a very long time constant situation and perhaps there we have got time to learn all the lessons and design

them into our products.

What Sam Wong was saying a little while ago, I think is really, on the production level, it's a very dynamic situation. Old problems are short time constant problems and really unless you've educated the guys down there to be aware of every single possibility, the problems on them,and it's passed and you're in a very costly situation before you even realize it is there. Okay, Bob.

SCHIESSER-CSDL: The next lessons learned is from Mike Gardos at Hughes Aircraft.

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<u>TOPIC:</u> POROUS BALL RETAINERS

DISCUSSION: STUDIES OF POROUS PHENOLIC AND POLYIMIDE BALL RETAINERS AND MATERIALS SHOW: (1) PURITY OF POLYIMIDE IS INHERENTLY BETTER THAN THAT OF PHENOLIC. (2) CONCENTRATION OF POLAR ADDITIVES IN LUBE IS REDUCED BY THEIR SELECTIVE ABSORPTION BY RETAINER MATERIAL. (3) BEARING LUBRICATION STRONGLY INFLUENCED BY RETAINER BULK POROSITY AND SURFACE CHARACTERISTICS, PLUS MANY OTHER VARIABLES. (4) FOR COMPLETE RETAINER IMPREGNATION BY LUBE, EVACUATE RETAINER DRY AND IMMERSE IN EVACUATED OIL BEFORE VENTING SYSTEM.

<u>LESSONS LEARNED:</u> FOR SUCCESSFUL BEARING APPLICATION, TREAT BEARING PACKAGE AS A SYSTEM WITH BALL RETAINER A CRITICAL ELEMENT OF THE LUBRICATION SUBSYSTEM.

GARDOS-HUGHES: I'm going to cut this real short because I anticipated a lack of time and I have a little write-up here which will go on sale in the cocktail lounge

out there. Seriously, I have a few extra copies for whoever is interested. This is just brief excerpts of what this contains and I would like to thank Al Freeman for abstracting that horrendously long lessons learned.

What I would like to say is I'm delighted to see the forthcoming cooperation,hopefully forthcoming cooperation,between the nuts and bolts guy and the surface chemist in that I see a need for it. I believe that Cpt. Neil Thomas' comments yesterday was just a harbinger of what was to come today because almost 90 percent of the problems that come up today are really surface chemistry oriented material problems.

I'd like to dispell the common belief of what the surface chemist thinks of the bearing technologist with his blacksmith apron and what the bearing technologist thinks of that money-wasting double-talking chemist who always takes the funds and never comes up with the answer. I think we'd better stop thinking in terms of stereotyping and start cooperating together. I believe that every team should have at least two people on the team, the bearing technologist and the material specialist.

Again, if you are interested, after the meeting I will be delighted to hand you a copy. If we happen to run out,which I seriously doubt,there are not that

many people interested, just give me your name and address on the back of your card and I'd be delighted to send you a copy wherever you are. Thank you.

FREEMAN-DRAPER: I'd like to second the comment that Mike Gardos made and I'd also like to point out that Draper Lab has done very extensive work in the area of bearing surface chemistry and has worked very closely with the people from the Naval Research Lab. And this has been going on for several years actually. I will certainly attest to the value of the technology that the Naval Research Lab was able to provide in this joint activity.

SCHIESSER-CSDL: The next one is Herb Singer again.

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TOPIC: ABRASIVE CONTAMINATION

DISCUSSION: DURING THE APPOLLO PROGRAM A NEW LOT OF BEARINGS WERE RECEIVED THAT WAS CHARACTERIZED BY VERY SHORT LIFE. IN FACT, MOST OF THE BEARINGS FAILED DURING THE BALANCING OPERATION WITH A EXTREME DARKENING OF THE LUBRICANT.

LESSONS LEARNED: UPON EXAMINING THE RACES, IT WAS FOUND THAT ABRASIVE WAS EMBEDDED IN THE RACEWAYS. THUS, DURING RUNNING, THE BALLS WERE ACTUALLY BEING LAPPED BY THE RACES. REMOVING THE ABRASIVES FROM THE RACEWAYS ELIMINATED THE PROBLEM.

SINGER-DRAPER: We get a lot of lessons and we

learn a lot.

Here's another example of process control. This came up prior the Appollo bearing but it really came to the fore in a group of bearings that were being processed by the Appollo program. Again, the bearings looked visually okay, like microscope, but when they were put on the balance machine they failed. They failed in a dramatic fashion. The lubricant turned black. Similar to what you would expect when you lap something, especially metal. The lapping compound becomes black.

In examining the races, it was found that abrasives were embedded in the raceway and these abrasives in the raceway were just locking the balls as the balls rolled over the bearings, rolled over the races and tore up material, just after you lapped it. We had a ball lapping process, which is not very good if you have a running bearing.

Again, we recommend in the specification and bearing manufacturers (?) is that the bearings are examined to be sure that during the final finishing operation, the lapping or honing, the bearings are examined to be sure there are no embedded abrasives left in the raceway. This is a simple examination just on a polarized light and these particles usually stick out like stars in a black field.

WONG-SINGER: I agree with you. In one of the other areas we found a lot of problems with the balls, so you can get the same problem with balls having aluminum oxide embedded and inability to move itself during the run-in. So it's not only raceways.

SCHIESSER:-CSDL: This comes to us from Lockheed and again Lockheed is not present.

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TOPIC: SMALL MOTOR MANUFACTURERS DO NOT HAVE THE KNOWLEDGE, CAPABILITY, EQUIPMENT AND FACILITIES TO HANDLE SMALL BEARINGS. OUTSIDE BEARING FACILITIES ARE NOT READILY ACCESSIBLE TO THESE HOUSES. NUMEROUS FAILURES HAVE OCCURRED IN THE PAST WHICH HAVE BEEN TRACED TO THE HANDLING DEFICIENCIES IN THESE SMALL HOUSES.

DISCUSSION: A PROCESS SPECIFICATION CAN BE IMPOSED ON THE BEARING MANUFACTURER TO PROVIDE THIS SERVICE. LUBRICATION CAN ALSO BE APPLIED BY THE BEARING MANUFACTURER TO THE DESIRED REQUIREMENT. BEARINGS WHICH HAVE BEEN PROCESSED CAN BE INDIVIDUALLY SEALED AND PACKAGED TO PREVENT CONTAMINATION AND/OR DAMAGE IN ALIGNMENT. THE MOTOR MANUFACTURER OPENS THE PACKAGES AS THEY ARE USED. THIS APPROACH IN BEARING HANDLING HAS ELIMINATED ABOUT 95PERCENT OF THE BEARING FAILURES IN HI-REL UNITS.

LESSONS LEARNED: CONTROL OF SMALL MOTOR MANU-FACUTURERS BEARING PROCUREMENT, HANDLING TECHNIQUES, AND LUBRICATION AND INSTALLATION PROCESSES IS NECESSARY TO AVOID PREMATURE BEARING FAILURE.

SCHIESSER-CSDL: It states a problem that they had with ordering small motors and we put it in here from the standpoint that you may be buying assemblies

with bearings in them from manufacturers and the problem that Lockheed had was they found that manufacturers of these small devices were not too well versed in bearing technology and they found they had to go back in and control that vendor to assure the proper handling of bearings. Any questions on that?

(Questioner did not use mike.)

SCHIESSER-CSDL: I don't know if these are (?) motors or what.

(questioner did not use mike.)

SCHIESSER-CSDL: I think the principle of the assembly with the bearings in it is worth pointing out, whether they're fan motors, (?) motors or whatever (?) bearings or whatever.

SCHIESSER-CSDL: This one is from Autonetics, Dale McLeod.

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TOPIC: QUALITY VERIFICATION TESTING

DISCUSSION: FOR VARIOUS APPLICATIONS AT AUTONETICS, BALL BEARINGS WERE TAKEN DIRECTLY FROM THEIR PACKAGES, AS SUPPLIED BY THE BEARING MANUFACTURER, AND WERE INSTALLED WITH NO RECEIVING INSPECTION OR TESTING. THIS RESULTED IN LOW YIELD AND POOR PERFORMANCE.

LESSONS LEARNED: BALL BEARINGS ARE ROUTINELY MEASURED AND TESTED BY AUTONETICS BALL BEARINGS LABORATORY TO VERIFY CRITICAL DESIGN FEATURES. THEY ARE FREQUENTLY CLEANED AND RELUBRICATED, IMMEDIATELY PRIOR TO INSTALLATION, TO ASSURE PROPER LUBRICATION.

AUTONETICS MANUFACTURING ONLY RARELY HAS TO DISASSEMBLE AN INSTRUMENT AND REBUILD IT DUE TO BEARING QUALITY PROBLEMS.

McLEOD-AUTONETICS: Our experience at Autonetics over the years is described here in the discussion and I think it's related to what Sam Wong was saying about watching the line in our own plants, but I think the bearing manufacturers have some of the same problems. Just because the first batch of bearings we order for a new application are good, without detailed incoming inspection doesn't mean the next batch is going to be.

As indicated here, we pretty routinely now assume that we'd better take a look at torque traces in our own labs, visual inspection and so forth to avoid problems like contamination, sometimes wrong ball size and other things that reach up and bite you and can cost a lot if you get further down the line.

SCHIESSER-CSDL: We've come to the end of the prepared part of the program and I have some additional viewgraphs that were submitted and I think what I would like to do is show them and briefly discuss them and open for general discussion. I want to thank the people that did send in lessons learned. We got late start asking for them and we at Draper made up a big list of lessons learned to fill the time and gradually

we withdrew

(Did not record.)

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TOPIC: CLEANLINESS OF GAS BEARING SURFACES

DISCUSSION: CLEANING METHODS AND INSPECTIONS ARE CRITICAL TO ADEQUATE START IN LIFE FOR A BG ASSEMBLY.

LESSONS LEARNED: CERTAIN SOILS, e.g., FINGERPRINTS ARE NOT REMOVED BY DEGREASING OR ULTRASONIC CLEANING IN CHLORINATED HYDROCARBONS. A SCRUBBING PROCEDURE IS NEEDED. THIS MUST BE BACKED UP BY THOROUGH MISCROSCOPIC EXAM IN BOTH BRIGHT AND DARK FIELD ILLUMINATION.

FROMM-DELCO: (Did not record) . . . we were just about on our knees. We went through a variety of problems, volatile contaminants that were choking the bearings, overslewing that was destroying at least the friction, the low friction surface, if not the actual substrate, lubricant migration, we thought corrosion of the beryllium material through the aluminum oxide. It was apparently a disaster.

We went through an extremely extensive development program. It went on for a year or more. Went through the whole surface chemistry skit. Got into reagent grade solvents. Even looked at bizarre things like RF ashing or total cleaning of the surface, trying to get a chemically clean surface before we put the boundary lubicant on. Eventually, however,

we found that our basic problem was we were simply not getting it clean enough at the outset in the micro sense. We did not have a large scale, mysterious chemical problem; we just weren't taking the crud off. And the typical clean room 30-power stereo microscope is totally inadequate to detect this. You have to look at with a good microscope with a variety of illuminations. Once you do that and you find that your inocuous dippings and ultrasonic and degreasings aren't really taking everything off, then you get a little tougher and all we have done is scrub the surfaces with lens tissues soaked in trichloride. We have apparently a design that is tolerant of relatively simple techniques. It's worked like a charm ever since.

I think there's a subsidiary lesson in this also, is that we look back a couple years later after some of these process changes had been made, we are able to detect where the change in field performance occurred, maybe three months after the process changes had been described. It was that lag time before the factory really got practiced in the way to do it right. So maybe that answers or addresses the point you raised there, Bill. Some of those same people are still building gyros, have been at it ten years, and that

touches another point.

SNEDEKER-BATTELLE: A couple of points I'd like to make. One of them is, as a chemist, I think I see the handwriting on the wall for all chlorinated and brominated solvents. I wouldn't recommend anybody developing a process involving chlorinated or brominated solvents. I think you are not going to be able to use them five years from now.

The second thing I found in the process of of doing some work on boundary lubrications and trying to get extremely wettable iron surfaces, that a lens tissue of any kind gave me a lot of trouble and we found quite by accident a good substitute that's quite economical. Xerox makes a grade or produces a grade of a solvent extracted cotton for cleaning their selinium drums and we use it routinely. It works damn well and you can scrounge it from the Xerox repairman when he comes around.

McHALE-NAVY: Relative to your ultrasonic cleaning problem, we're in a process at Alameda of learning a lesson. Mainly we are finding the people are using the ultrasonic cleaning procedures and yet they weren't really getting cavitation. Cavitation wasn't occurring. And Alameda is developing a method whereby using a temperature sensor, you can actually

plot out and know when you have cavitation.

Part of the cavitation process is the cleanliness of your cleaning solution and all too often we find in all of our NARF's that the material in your ultrasonic cleaner eventually becomes contaminated and yet they keep using it. So we are trying to develop some kind of a cutoff point on the material at which automatically they will get new stuff in there.

FROMM-DRAPER: Our cutoff is one bearing. You simply throw the material away after cleaning one bearing.

DARRIS-SPERRY: The process of cleaning and scrubbing with various materials has been a problem. We found quite by accident that the lens tissue does provide a reasonably good boundary lubricant because of the variable amounts of diactylthiolate and that was a job to find out why some gyros ran for many, many hours and some didn't even get off the pad on the first start. Then you start to control the amount of diactylthiolate and you find you can't because the paper industry is bigger than you are.

Then it gets down to a point where you have a real cleaning , we found that the ultimate cleaning now in our processes for the gas bearing is plasma cleaning with the (?) process which has been

reasonably satisfactory.

GARDOS-HUGHES: A comment for the Navy. You may want to consider using the combination of ultrasonic cleaning and vapor degreaser. There are some really some neat little commercial apparatuses that are available which is the ultrasonic portion of the cleaning apparatus even though the solvent is somewhat contaminated by some soluble contaminant will still remove the particulates and then when you raise the bearing components after the vapor phase, that will be neatly washed out by the pure vapor condensing unit.

ORLANDO-HONEYWELL: I have a couple comments to make. My experience is a lot of gas bearing engineers do not actually with their own two hands put gas bearings together and then test them. They depend very much on the technicians. One of the things you can find from technicians is they spend tremendous amount of time cleaning things that are not important and missing what is important. So my first lesson learned is that now and then when we have a problem, I guess I have to do it with my own two hands, that's number one.

Number two, we don't use ultrasonic cleaning. We know it can damage the bearing if you ultrasonic and then make particle count you will get down to a level and never get below that level and have to go

to washing. So the other thing is we do use lens tissue, we do (?) extract all the lens tissue we use, when we have a reproduceable process. When we have a trained technician who looks for the critical things. We have not found the cleaning process to be anywhere near as significant as I think has been indicated here, if we keep one thing in mind. There is no such thing as an asbolutely clean surface and there never will be. So all that we are boking for is something that will reach a certain level and hopefully a little better than that. And we constantly try to get a better method. But this is not going to be a perfect clean surface. Nature won't allow that. If we get reasonably clean surfaces, we can put this boundary lubricant on, they will set up chemically if you use a boundary lubricant so that the surface is boundary lubricant, that lubricant will not wear off in a reasonable time if the bearing is properly designed.

Now all that I am saying may not apply to ball bearings, Herb. But I just want to say that it's not a black magic to build gas bearings that work over a very long time and I think this is true for ball bearings as well.

SINGER-DRAPER: It's interesting that gas

bearings as well as ball bearings have surface chemistry problems. One thing talking about clean surfaces on ball bearings, you know you've heard I'm a strong advocate for surface chemistry affecting the bearing and we went to a little program and say, well, how do you clean the surface and we decided that the best way to clean the surface is to remove everything that's on the surface using flow discharge, which is, as everybody will agree, is a real good cleaning technique and lo and behold, using flow discharge, the flow discharge in cleaning the races and balls and assembling the bearing as is, the bearing failed in a very short period of time. We had to go back and add an known contaminant, which at this time was zinc diothiophosphate, which is a sulfur zinc phosphate and the bearings are now, we got about 60,000 hours on those bearings.

FROMM-DRAPER: One of the few times in our careers I agree with Vin Orlando completely. It isn't like magic. If you get a process that works, it can be quite simple. The problem is knowing when it works. Because you have to get lots of field experience before you know it's good. That's the difficulty.

SCHIESSER-CSDL: I had an interesting one submitted by Lockheed that for some reason didn't get into a viewgraph. And it has to do with a problem that maybe people don't have, but maybe some people do and I'd like to just read it. Many items used in the build and processing of gyros are expendable items that are bought through a company's purchasing depart- ment on a simple PO. Unlike those items that are brought in to a specification or a spec drawing or what, and I don't know why they don't have a specification on all of those, but anyway -- that are considered critical or peculiar. As a result, the purchasing agent may decide to shop around finds he can buy a different brand of detergent for less money or isopropyl alcohol is cheaper from the corner drugstore than reagent grade alcohol.

These seeminly harmless changes get into the gyro processing system. As a result, the detergent may not rinse off as well or the existing procedures may leave a contaminating residue. Much of this problem takes many months of expensive time to resolve.

The lesson they learned was that strict control of purchasing departments must be incorporated into any system involved in building highly reliable inertial grade gyros and any changes they recommend most certainly

should be first evaluated to determine the acceptability to the existing processes or if changes are necessary. So that people outside of the general activity might give you problems if you don't have the control.

What I'd like to do now, as I said, we have a number -- do you have a question? Herb's got a comment.

SINGER-DRAPER: I just have a comment on that. We've talked about using only reagent grade solvents, but you will find that some cases just specifying reagent grade and getting a bottle that is marked reagent grade doesn't mean that it is reagent grade. I recommend strongly some sort of form of control set up be made for lots of solvents (?) .

To give an example, we bought some reagent grade methol alcohol. It had all the things on it that it's reagent grade. Fortunately we have technicians before they use a solvent take a whiff of it and this one technician says no way this is methol alcohol. And we checked it and sure enough in this method alcohol it was loaded with water, formaldehyde, acetone and a few other things that we couldn't recognize.

WONG-SINGER: I'd like to just confirm what Herb has stated that many times our reagent grade

material we get in 50-gallon drums do contain like freon contains a high level of silicone, higher than the spec allows and it comes in that way. We found out, we actually ended up distilling our own freon in order to get down to less than 2 or 3 parts per million. We distill it down to less than .05 and then feed it right into the gas bearing cleaning process. We find out that it's necessary to recheck and check it every week, the system that you're using. It can get contaminated very easily.

DENHARD-DRAPER: He said the magic word.

(?) You're speaking of the PCA grade failing as well?

SINGER-DRAPER: The question before us, and I guess it was raised just a little while ago is that the EPA are looking into the banning of all uses of freon and the laboratory I guess pioneered the use of freon in this area back in the 50's, the reason being it wasn't a very good solvent and that it had a low surface tension so they could get under and lift particles and flush them away, so to speak. But it wasn't a good solvent and that meant that it wouldn't attack a lot of the materials that we build into the instruments, the epoxies and the (?) compounds

and what all else, so that in addition, the freon was tolerated by humans in their work area far better than most solvents. It was a poor solvent, but it was effective for a number of cleaning operations. And the question of replacing that material like that is a very big question right now.

SNEDEKER-BATTELLE: One comment with regard to freon. I notice under certain conditions, particularly in Columbus in the spring when it's raining a lot, the use of freon will tend to chill the metal surfaces and cause condensation if the humidity in the lab gets much over 50%.

SCHIESSER-CSDL: That's true. We attempt to keep the humidity in our labs below that, if you have a good contractor that builds your lab.

Taking just a few minutes to run through some backup slides, if you're interested and maybe Herb who has got them can quickly go through them to show what some other lessons learned are that might be of interest.

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TOPIC: SMEARED CARBIDES

DISCUSSION: AS PART OF THE KG-80 EVALUATION PROGRAM, A NEW LOT OF 440C STAINLESS STEEL BEARINGS WERE PURCHASED FOR THE LIFE TESTING. THE RACEWAYS OF THEIR BEARINGS WERE HONED TO GIVE GOOD GEOMETRY. THE LIFE OF THE BEARINGS

WAS EXTREMELY SHORT WITH BOTH TERESSO V-8 AND KG-80.

LESSONS LEARNED: VISUAL EXAMINATION OF THE RACEWAYS REVEALED THAT THE CARBIDES WERE SMEARED BY THE HONING OPERATION. REFINISHING THE RACEWAYS BY A MODIFIED HONING PROCESS TO ELIMINATE THE SMEARING RESULTED IN LONG LIFE BEARINGS.

SINGER-DRAPER: Here's a case in which there's always been a look into how better to finish metal parts and we got some bearings in at the time we were looking into replacement of V-8 and KG-80, running a program, and the bearings were honed with good geometry, but when we looked at the bearings, by the way, they gave poor performance. We looked at the bearings and we found that the carbides, not the matrix, but the carbides were smeared, were actually flowed in the direction of the honing operation. This caused the poor running performance. Refinishing the bearings by another honing technique eliminated the problem and we now have long life bearings.

One other point I want to make here and I hope I'm not taking some thunder away from the bearing manufacturers, but I strongly recommend in a case like this where the manufacturer may change some technique, but the user doesn't feed back to the bearing manufacturer their experience with these lots. You all may get the

same problem over and over again. You just use the bearing, find short life, throw the bearings away, and blame the bearing manufacturer, you're only hurting yourself.

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<u>TOPIC:</u> UNACCEPTABLE BALL BEARING DYNAMOMETER EVALUATION DUE TO BALL DEFECTS.

<u>DISCUSSION:</u> THE SCREENING OF BALL BEARINGS BY LOW SPEED DYNAMOMETER TESTING UNCOVERED DAMAGED BALLS IN A GROUP OF BEARINGS. REPLACEMENT BALLS FROM THE MANUFACTURER RESULTED IN THE SAME PROBLEM, AND INSPECTION UNDER HIGH MAGNIFICATION WAS UNREWARDING. REVIEW OF THE PACKAGING FOR SHIPPING WAS REWARDING AND PROPERLY PACKAGED BALLS RESULTING IN ACCEPTABLE BEARINGS.

<u>LESSONS LEARNED:</u> SCREENING TESTS AND PROPER PACKAGING WILL PROTECT BEARINGS FROM THE POSTAL SYSTEM.

SINGER-DRAPER: This is a shipping problem. We ran into some problems; we were replacing balls and bearings and we could not get the bearings to pass low speed dynamometer which does depict metal damage as well as dirt and so forth. It turned out that the problem was that the bearings, the balls were shipped through the mail with no proper packaging and they evidently got squashed by the way the mail handlers handle the mail and revising the packing technique eliminated that problem.

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TOPIC: TCP TREATMENT

DISCUSSION: BEARINGS FOR A GYRO WERE DESIGNED TO HAVE A SMALL PITCH DIAMETER, LARGE BALLS AND INNER RACE ROTATION. WITH THESE DESIGN PARAMETERS, THE SPEED OF THE BALL COMPLEMENT IS LOWER THAN BEARINGS DESIGNED WITH A LARGE PITCH DIAMETER, SMALLER BALLS, AND OUTER RACE ROTATION. DURING THE BALANCING OPERATION, (THE WHEEL WAS BALANCED AT 6000 RPM), THE BEARINGS FAILED CHARACTERIZED BY METAL BEING TORN OUT OF THE RACEWAYS.

LESSONS LEARNED: IT WAS DETERMINED THAT ALTHOUGH THE WHEEL WAS RUN AT 6000 RPM, THE RELATIVE SPEED OF THE BALL TO THE RACES WERE LOW DUE TO THE DESIGN PARAMETERS AND EHD FILM WAS NOT ESTABLISHED UNTIL A HIGH ROTATIONAL SPEED WAS REACHED. TCP TREATING THE BALLS AND RACES ALLOWED THE BEARING TO OPERATE IN THIS LOW SPEED REGIME WITH NO FAILURES.

SINGER-DRAPER: TCP treatment has been known and shown many, many times it will ensure, will improve the life of bearings running at slow speed. In fact, we had a case where we designed a gyro which we had a small pitch diameter, very large ball, inner race rotation. The wheel was running at 24,000 RPM, but the large ball, the small pitch diameter -- a large pitch diameter, I'm sorry -- we had slow surface speed.

During the balancing operation, the bearing was not TCP treated, and it will never happen again. During the balancing operation,the bearing failed, typical of what we see at low speed running. Metal parts being pulled out, reddish-brown, looked like threading corrosion. Simple fix. We just TCP treated it, and the problem went away.

SNEDEKER-BATTELLE: I'd like to make a comment in support of what Herb is saying, I am now in the process of doing a basic research program. It deals with the determination of reaction rates and mechanisms for TCP on iron surfaces and we found that it takes TCP in the order of minutes to form a viable film, even at temperatures as high as 300 degrees, not orders of seconds or microseconds or milliseconds, as many people think. And frankly, I think in a high speed or low speed for that matter, but particularly high speed bearing, if you are not TCP pre-treating, you are running a real danger of not getting a TCP film. I think the TCP reaction from the oil on the surface is taking place during the soap period and isn't taking place, as many people think, during the actual contact process. TCP appears not to react that fast. You've got to have your film there first or you're dead.

SINGER-DRAPER: Let me comment. We recommend, and have done some experiments on a pin and disc machine which you run a pin on a flat plate and measure the friction and wear characteristics and it turns out that we need three days at 225° for 440C to get an optimum and a wear about durable. It turns out to be a phosphate film as NRL demonstrated on the OJ spectrometer. To get a durable film on the surface,

it takes 15 days for some reason on 52100, even if 52100 is supposedly more reactive than 440C. I used to call it a fortnight and a fortnight is 14 days. We found in this machine that 15 days were needed for 52100 at 225°. This is just for TCP. We wash off the TCP afterwards and then run it with the oil. But one thing I like about TCP, although TCP may not be the only boundary lubricant you can put on a bearing, is that you can leave the parts in TCP at room temperature or even at elevated temperatures and you do not affect the metal parts. They don't corrode, doesn't chemically attack the parts that will affect the geometry of visual appearance.

SCHIESSER-CSDL: Before I turn this over to Oscar McClannan, on behalf of Colin and myself, I'd like to thank you all for participating in the meeting.

McCLANNAN-NAVY: I just want to take a minute to thank you for your participation. It's really rewarding to the planning group to see the participation that we get in these workshops. The crosstalk, the exchange of information is really wonderful. And this is what our conference is about. The exchange of information, the data that we have in our own environment we can pass it on to someone else and hope that it will

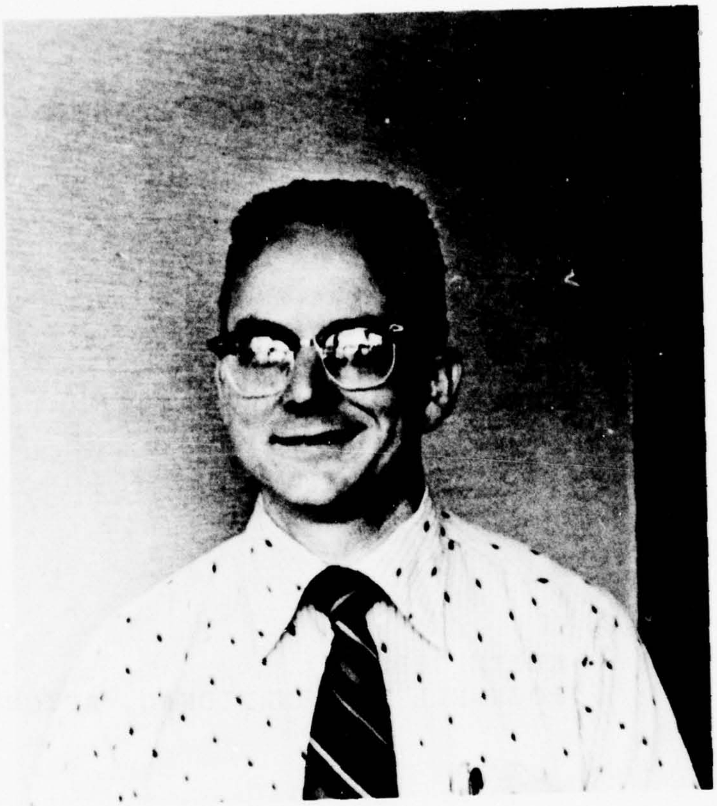
help them. This year we did not get any particular problems someone might have. I want to invite you to send your problems to the chairman of the Task Group and we will see they are published in the next newsletter.

Also we want to invite you to during the year think about next year's conference and if you have lessons learned, jot them down, send them to the Task Group and we can use them and get our workshops established a little bit sooner next year. I hate these last minute panics.

Thank you very much.

LIFE CYCLE COST LESSONS LEARNED WORKSHOP

CHAIRMAN



KEITH GIBSON
ROCKWELL INTERNATIONAL CORP/AUTONETICS DIV.
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SESSION V

LIFE CYCLE COST LESSONS LEARNED

THURSDAY, 27 OCTOBER 1977

CHAIRMAN: KEITH GIBSON
ROCKWELL INTERNATIONAL, AUTONETICS DIVISION

BURKE HALL - DENISON

TOPIC: INTERPRETATION OF LCC DIFFERENCES IN EVALUATING LCC RESULTS OF TRADE-OFF STUDY.

DISCUSSION: WHEN THE OUTPUT OF A TRADE-OFF STUDY SHOWS A SMALL DIFFERENCE IN THE TOTAL COSTS OF ALTERNATIVE DESIGNS, FOR EXAMPLE, $500,000 OUT OF A TOTAL OF $30,000,000, A TYPICAL MANAGEMENT RESPONSE IS THAT THE DIFFERENCE IS TOO SMALL TO BE MEANINGFUL. HOWEVER, EVEN A SMALL DIFFERENCE MAY POINT TO A DESIGN FEATURE, WHICH, IF PERTURBATED, MIGHT RESULT IN A COST LESS THAN EVEN THE LEAST OF THE PREVIOUS ESTIMATES. CONVERSELY, WHEN A TRADE-OFF STUDY SHOWS A LARGE DIFFERENCE THE CORRECTNESS OF THE INPUTS IS QUESTIONED.

LESSONS LEARNED: A CAREFUL EVALUATION OF THESE RESULTS IS REQUIRED TO DETERMINE THE CAUSES AND SIGNIFICANCE OF THE OUTCOME.

SHARP-LITTON: I'd like to read the discussion. When the output of a trade-off study shows a small difference in the total costs of alternate designs, for example, $500,000 out of a total of $30,000,000, management's response might be that the difference is too small to be meaningful. However, even a small difference may point to a design feature which if perturbated, might result in a cost less than even the least of the previous estimates. Conversely, when a trade-off study shows a large difference, the correctness of the input is questioned.

Lessons learned. A careful evaluation of these results is required to determine the causes and significance of the outcome.

I think the lessons learned could be stated in another way. As an analyst, be prepared to identify

the major cost drivers and to support the value you have used in your input to your analysis.

The hypothetical example of lessons learned would be a cost study to determine the potential savings available from a change in intermediate maintenance concepts.

Let's say that the maintenance concept change would permit the replacement of a circuit card in the sealed platform area. The results of the analysis would show a savings by the replacement of the cards. Then you would show a savings by the replacement of the cards. Then you would probably look at it and be encouraged by the results and you would want to extend that, and disregarding the maintenance risk involved with replacing the platform, and then the savings would even be greater.

So, interpreting the results would occur by breaking down the final number from the trade-off study, into the three component parts, design, acquisition and operation. The part that makesthe largest delta would in turn be examined for the life cycle cost element which in turn poses a major variation.

By using this process, the variable which is making the most impact can be identified. In the previous example, (?) would be the main variable.

It would be interesting to hear some different

approaches to the intepretations of life cycle cost results.

GIBSON-ROCKWELL: Let's see if we can get some discussion. When you find that the difference between one and the other might be a significant dollar value, the percentage of the total dollars you're predicting might only be 1 or 2%. Do you consider a 2% difference significant even if it might be a million dollars. Is a million dollars significant when it's only 2% of your total program, as an example? Questions or discussions?

Before you put the mike down, Jerry, what dollar values were you talking about in your experience?

SHARP-LITTON: Well, if you include the platform, it seems like there was a difference of two million dollars. The total sum was close to fifty million dollars.

GIBSON-ROCKWELL: Is that significant? Has anybody had this problem in presenting their studies?

(?) - DRAPER: A recent program that we worked on, I've encountered the same thing where we've tried to make a distinction between throw away and repairable modules and our life cycle cost curves indicate that there is probably a toss-up, maybe a slight savings to

go throwaway. Now what determines the decision that we make, I think it's based primarily on the credibility of the amount of confidence you have in the information that you've assigned to each of the parameters and in our particular case, what we are going to do is try and broad band or extend the range of values to those cost parameters or those cost elements that we feel are probably,we had the lower confidence in. And in that way try and determine what our risk might be in making one decision over the other.

GIBSON-RCKWL:Bill also mentioned in our life cycle cost Task Group meeting Tuesday and maybe many of you seen he presented a chart by Boeing. He's going to allude to it; they're talking about it here again a little bit later this morning. Where program costs are essentially fixed pretty early in the program, so if you get down to doing your trade-off studies in the production time frame or just pre-production, you have so many of your costs already fixed for you that the only thing you're dealing with, the variable you've got to play with is somewhat a small percentage of the program you can affect at that time. Are there any other comments on this point?

Okay, we'll just move right along to the next

one. The next two or three subjects deal with life cycle cost modeling one way or the other. First Dave McDonough, who is the project engineer for the Avionics Section of Dynamics Research Corporation will lead the discussion. His responsibility at DRC lies with life cycle cost analysis, plus reliability and maintainability tracking. Dave.

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<u>TOPIC:</u> APPLICABILITY OF LCC ANALYSIS IN RELATIVE COMPARISON.

<u>DISCUSSION:</u> ANALYSIS OF THE RELATIVE COST DIFFERENCES FOR ALTERNATE APPROACHES RESULTED IN CERTAIN EFFICIENCIES:

MANY COSTS WHICH ARE IDENTICAL (OR TRIVIAL) FOR ALL ALTERNATIVES ARE NOT CONSIDERED.

ECONOMIC ENVIRONMENT CAN BE LARGELY IGNORED.

THERE IS GREATER EMPHASIS ON THE MOST RELEVANT COST DRIVERS.

MUST BE USED IN CONCERT WITH ESTIMATE OF ABSOLUTE LCC.

<u>LESSONS LEARNED:</u> LCC MODELS CAN BE SIGNIFICANTLY SIMPLIFIED IF RELATIVE COMPARISON IS ACCEPTABLE. (LESS "HARD TO GET" INPUT DATA).

BECAUSE MODEL IS EASIER TO USE, IT'S MORE LIKELY TO BE USED.

THIS APPROACH IS ESPECIALLY APPLICABLE TO COMPARISON AMONG NEW OR PROPOSED EQUIPMENTS.

McDONOUGH-DRC: Thank you, Keith. I'll give you just a minute to read the first part of that. What

I'm talking about is an approach to life cycle cost analysis, which includes several things. We're talking about determining the relative cost differences as opposed to the absolute life cycle cost. Now, before anyone says, no, you can't do that, it's really just a part of the thing.You also have to determine the absolute cost.

Now, what we have done and are able to do is ignore some of the costs that are either so small that they're trivial or are identical for two different things that might be being compared.

Another aspect, as you can read, is the economic environment can be largely ignored, since you are comparing two things and you are comparing over either the same time frame or the same production qualities. You can assume, and I think rightly so, that there will be no difference, or just a small difference.

One of the other things that sort of appears here is that the cost drivers appear more clearly. They are not masked by some other numbers that may make the cost drivers seem to have a smaller effect than it really might, in the relevant sense.

As I said, you have to use this in concert with the estimates of the absolute cost so that you know what the total cost would be as well as what the relative

differences will be.

What we feel can be learned from this is that the model itself can be significantly simplified as far as input data goes, because input data is really one of the most difficult areas, especially when you're talking about a new system or systems that do not exist. You have to attempt to predict what a lot of the parameters will be and there's fairly low confidence on some of that.

Because the model is easy to use, it is more likely to be used. I think everyone would agree to this.

I think the last is the most important because it puts a bound on this approach.To do this when you only have one alternative does not make sense. When you are comparing one thing to another, either one equipment to another or one approach to another. This is when it has validity.

O'NEAL-ROCKWELL: I've used this technique doing some analysis, and I find when you are working directly with the designer that it really comes through to them a lot better and they really identify then their cost drivers. It's amazing how many new ideas they have when they discover a process that did something

in the design is a cost item. As you say eliminates all the other stuff that generally hides it to where it brings out to them that they've got a problem there and they can work it.

(?) - ALD: My question is on the economic environment being largely ignored. Are you talking about the inflationary rates that take place or standard or what?

McDONOUGH-DRC: There's two things, really. Escalation due to inflation is one and when you are comparing two things that are going to be -- you're going to compare two alternative equipment choices that would be used on the same time frame. You're going to use one or the other. Then you can ignore the effect of inflation because it would affect them both equally.

(?) : Dave, how do you know until you've done this study that you're not eliminating something that's important. For example, the thing that was just brought up. If it's over the same time frame you can eliminate the consideration of inflation perhaps but you have to look at that to start with to make sure you aren't expending a different rate over different times, don't you?

McDONOUGH-DRC: Yes, that's true. The other

aspect, the other economic aspect that has a large effect is the quantities of production and you can sort of expect that if you are talking about buying 500 systems versus 2,000 systems, that there will certainly be a difference. There would probably not be a difference between the two different types of systems. This may not be true, though, all right? And what I'm saying is you definitely have to reevaluate your assumptions based on what you're actually doing. These are assumptions of a particular program and as you go along you have to revalidate them to be sure they still hold true.

(?) ALD: If only the parts, your piece parts that you're going to be replacing in the future as failed items, you know, the inflationary rates I'm speaking of were manpower-type things. But what about the piece parts that you have to buy downstream, you know, with the inflationary rates and the costs going up, do you take a look at those cost drivers?

McDONOUGH-DRC: If I understand the question correctly, yes. But again, I'm primarily talking about comparing two or more alternatives and if you have a case where one alternative you're not going -- for some reason you're not going to have to buy piece parts because possibly it will be throwaway and you buy other modules rather than piece parts, then you'd have

a difference, all right? Let me restate that. In one case you had to buy piece parts and in another you didn't; you would have a difference, yes. What effect that would have, you would have to look at. I suspect it might not be that great, but you'd have to look at it.

Very quickly, the next chart. I've just listed some of the items that we feel can be ignored. I won't bother to read through them. If anyone has any questions, I'll be glad to answer them, but I don't think there's anything too startling.

TAYLOR-HONEYWELL: When your new facilities cost, I think we're talking in terms of facilities for the government, such as the Corps of Engineers would build, and not facilities as they relate to the contractor, so I think it is important that you look at the new facilities that would be required to support the equipment.

McDONOUGH-DRC: Okay. In this particular case I really was talking about contract facilities and the feeling is that those costs are amortized costs, the acquisition cost.

(?): If you were talking about the cost of facilities for the government, again I would suspect

that you'd have to go back and look and see if the alternatives made any difference, and if there was a difference, alternatives are then considered. Is that what you are saying?

McDONOUGH-DRC: That's generally true in any analysis. You have to reevaluate to be sure that your assumptions there are holding true.

GIBSON-ROCKWELL: The next topic or the next discussion is very much along the same lines, so why don't we move on to Bill Beaton. He has some similar experiences. Bill is the reliability and QA project engineer at Draper Labs, one of them at Draper Labs. He's responsible for reliability and quality requirements in addition to life cycle costs. Bill.

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TOPIC: LIFE CYCLE COST ANALYSIS DURING CONCEPTUAL AND ADVANCED DEVELOPMENT PHASES.

DISCUSSION: DURING THE EARLY PHASES OF A PROGRAM, THE LCC STUDIES MUST BE ACCOMPLISHED RAPIDLY TO PERMIT FEEDBACK OF RESULTS TO DESIGNERS. INFORMATION NECESSARY TO PERFORM THE LCC ANALYSES IS OFTEN SKETCHY AND RAPIDLY CHANGING. AT THIS TIME WHAT IS NEEDED ARE SIMPLE MODELS THAT CONTAIN ONLY THE MINIMUM COST FACTORS NECESSARY FOR A MACRO ANALYSIS. IN DOING THIS MUCH LESS SOPHISTOCATED COMPUTER SYSTEMS CAN BE EMPLOYED AT A MUCH LOWER COST.

LESSONS LEARNED: BY SUB-DIVIDING A DETAILED LCC MODEL INTO SEVERAL SIMPLER MODELS AND PROGRAMMING THEM INTO A SMALL PROGRAMMABLE CALCULATOR, THE LCC ANALYSES WERE ACCOMPLISHED AT LOW COST AND MORE RAPIDLY. ONE OF THE MAJOR ADVANTAGES OF THIS TECHNIQUE IS THE NEARLY 100% AVAILABILITY OF THE COMPUTER TO THE ANALYST.

BEATON-DRAPER: This particular lessons learned concerns itself with life cycle cost modeling or alternatives to complex models and it relates to the type of model that one might use in the front end of the program. And by front end, I'm talking about the conceptual design and early development phases. In establishing and defining the type of model you want, one has to recognize what the program requirements are, has to be constrained by the computational facility, and by the availability of the computational facility. And what we've done is try and identify because of the uniqueness of our role as being design agent is to try and identify only those cost parameters that are related to the design. In other words, if the design can't influence the cost, there's no point in our putting it in our model.

And as a result of this, what we've been able to do is come up with very simplified life cycle cost models. It has also enabled us to then program them on small hand-programmable calculators, like the SR-52 and the main advantage on this is that it provides us with a continuous availability of the computer.

There are only several-- I've got five equations there that I needed to model the life cycle costs and each of them has been able to be programmed onto magnetic cards, which has been compatible with the SR-52. Acquisition costs, the deployment costs; this happens to be the way I broke out the life cycle cost models into those three areas. Acquisition, deployment and operational support costs.

Additional equations that are needed are (1) to determine the quantity of spares that you might need to support your system out in the field and the other series of equations that has to be modeled are other ones that are used to estimate the failure rates, if in fact you're not relying on historical data.

What this is, is the life cycle cost model. If you look at the bottom line, it's strictly a summation of the acquisition, deployment and operational support costs and within each of those terms, starting from the top, it breaks down into those cost elements that we consider. And you can see they are all very strict, very simple additions,straightforward arithmetical operation, and very simple to program onto a small computer.

The attainment, attaining failure rate data, if you don't have a historical file, then the traditional

method or the standard method or the most acceptable method is to utilize MIL-HBK-217, and if you look at the equations in there, there are only four forms, three forms of equations that are used and they will allow you to calculate the failure rate of just about all of the discreet parts.

In the first one, all of the monolithic IC's, and the equations in there for those are of the form noted. And whether a factor or a term in there is applicable or not it involves inserting a one, if it's not applicable.

The same is true of the semi-conductors and passive components, they're all of that form shown there and the factors, if they don't apply, you insert a one. Similar, too, the magnetic devices.

The other thing you have to wrestle with is the spare sufficiency requirement and traditionally the (?) is used, but in our case, we elect to use a (?) or you can also use a (?) expression. That happens to be a standard program with the TI inventory program library.

The next one just identifies the (?) distribution which again is a standard statistic.

JACKSON-NORTHROP: In one of your slides you had an equation of ten times the operational support

cost. Would you explain that factor of ten?

BEATON-DRAPER: That model happens to be unique to a particular program we are working on and I used it for illustrative purposes. That factor of ten is to account for the service life; it was a ten-year service life, and it was applied to recurring costs over the life of the hardware.

(?) Let me ask a question again, we also asked previously about eliminating particular cost categories from your models beforehand. Can you be sure that you are not forgetting something?

BEATON-DRAPER: What I intended to do is take a more complex model, go down through it utilizing it as a check list just so I wouldn't overlook something and then based on the information that I had on the program, I would eliminate and drop off those cost elements I felt were not going to be conducive to design influence.

GIBSON-ROCKWELL: Comments, questions, any other experience?

(?) Northrop: Can CSDL comment on how successfully they've used the life cycle cost process to date?

BEATON-DRAPER:I can't comment on it from a point of being able to show that our estimates are realistic because the program that we are working this

thing on is still in the very early design stages, but all life cycle cost estimates are -- the credibility of them at least -- determined by the -- how well you've modeled in those variable factors that can influence the cost and how credible the information is that you've used to support them. That's a big bone of contention, what type of rates you use, whether you use $10 an hour at a facility or $20 an hour at a facility, has a lot of bearing on the ultimate life cycle cost. But from our point of view, those costs are somewhat irrelevant or immaterial to our objectives because what we are trying to make is relative comparisons between two or more conceptual design approaches.

As I mentioned earlier, our primary interest is in only identifying those costs that the design can have some influence on. Like I can't answer your question except in a roundabout fashion because if I've overlooked a significant cost parameter, then I have no knowledge of it at this time.

GIBSON-ROCKWELL: I saw a lot of smiles come over peoples' faces when you brought up that question. It's one that's thought of an awful lot, but maybe it's an advantage in this life cycle cost game,we predict life cycle costs that are going to occur out over the next 10, 15 years, but even if we are absolutely perfect

in our predictions, we'll never know, because things always change before we get there. So it's, I think our credibility lies with how good we do our homework and how well we consider all of the facets that are applicable to the particular study.

HAMMON-FTD: Recognizing that contractors generally cannot operate with a 7% profit that you show, classicially the aerospace industry makes its money on the parts that are supplied later. How do you account for this in the factor in your work as well as recognizing that the parts that they procure or printed circuit boards or assemblies that they assemble during manufacture, during production, generally are not available except at a very high cost five years after production when the Air Force runs out of its spares?

BEATON-DRAPER: I'm not sure I understand the point you are trying to make, but let me at least start it and if I'm not, then you can interrupt and correct me.

The model that we are putting together is not one to try and estimate what the life cycle costs will be of the system that we are putting together. It's an estimate of what that system might cost when it goes into volume production and the cost factor that we use are being obtained from industry. We look at the various

processes that go on in assembling a board, for example. We look at the, and we try and estimate those to the best of our ability. And where we are lacking in production knowledge, we've utilized industrial support contractors. Utilized those type of quotations, the piece part estimates that we've obtained from vendor quotations. The actual costs that we are using are based on current dollars. This is the result of a constraint that was put on us in the contract, that we would estimate the cost of the system in terms of current dollars, not accounting for inflation. The 7% profit was an item that happened to be agreed to with the program office and as being a reasonable one in trying to estimate what the acquistion cost would be.

HAMMON-FTD: The point that I was trying to bring out was the fact that the profit just isn't necessarily in that 7%, but it's when you have to go back to the contractor and ask for that part to be made again, when he has already shut down his production line and then he has to face start-up costs again for manufacturing that board or that assembly.

BEATON-DRAPER: That's true on just about most programs of any longevity that you run into a situation

where either you are going to have a part that's become obsolete and there are several ways -- there are ways around it. In this program, there happens to be something of concern to some of the designers in trying to make a judgment on whether we have throwaway type module or whether we have a repairable module. If they're throwaway and for some reason downstream the vendor decides not to, or a vendor decides not to build any, then you are sort of stuck with trying to cannabalize your inventory and that also can be true of a piece part. But it's a risk that all programs, I think, has to take.

PALMER-DRAPER: I think I can add something. If this goes forward to a point where we go into production and it would be on competitive bid, so that you're not looking at sole-source situation on production.

(?) Yes, you can compete to production, but ten years later when it's already in inventory and you classically say, well, I've got to retain for three more years before we get a decision for a new form fit function standard INS ten years later, you have a new name for it, and we wait three more years, you have to keep airplanes flying, so we have to go out and fix it again. You generally then are very much constrained to go back to that original equipment manufacturer and

that's where he says, aha, I've got you.

Unless it's a particular unique item that was included originally in the design, the government would own all of the procurment package.

(?) What you're saying is true, and it's a concern on many programs, the options you have you either buy all of your expected inventory of spare parts when you make your initial procurement and then stow them in a warehouse somewhere, or else you allow for design modifications downstream to permit you to redesign around the problem or you go to cannabalization of inventory. There's nothing unique about our approach versus what's happening in real life.

(?) Or a final one is that you can go out andreprocure -- go out and bid again.

(?) For this particular package of ours, it's intended that way that we have interchangeability of all components between several sources.

(?) We started talking about life cycle cost models and the way we could simplify it and of course we want the models to reflect as best we can what the real world is going to be and in many cases, we have this situation that you brought up very apropos where spares costs are going to be much more when you buy them

five, ten years later down the road than the unit cost is when you buy it new. I think this is one difference that you've got to ask yourself, do you want your model to consider that? Do you want a simple model that will be easy to handle and we can ignore that for the particular question or study in point, or do you want to go to a model -- we're going to hear a little bit later about the CRIER model that the Task Group has put together -- that people have complained about it's too complicated of a model. In that model, one of the complications is that we have factors that can be put in there to accelerate the costs of your spares over the years. So I'm glad to hear this discussion and it's really the question -- how complicated do you want your model? Now any other? Al.

BRANN-LITTON: I have a question. I've never seen a life cycle cost study that was subtle and maybe -- I used to do them several years ago and very deterministic, very simple life cycle cost studies and they have become increasingly more sophisticated and I'd like to ask the people that do them every day, can you give me an example of one that was subtle where there wasn't a very obvious trade-off with respect to the test equipment or the fact that there wasn't one SRA that happened to cost about seven times as much as any of the others and so when you

pump it in the pipeline, it's fairly clear that it's the one you want to do at the intermediate level, etc., etc. I've never seen one where you could be off by not even -- by quite a bit, and it wouldn't make that much difference. And I'd be interested if there is such a thing as a subtle life cycle cost where playing around with one little teeny parameter really made a difference in the cost of the program in the long run. I contend that that isn't true. And in fact, they can be very simple, very deterministic. Now, when you are modeling a depot, like (?) or something, and everything can be so you can use all the actual distribution, your histograms of real data and all that, that can be real neat. Even there I found -- I mean my experience was that those kind of models didn't get used very much because people rapidly found out that you could do most of the planning with a fairly simple set of equations. I'd like to see how you feel about that.

BEATON-DRAPER: My comment would be there's a difference between sublety and simplicity. The model that we happen to be using on this L-6 program, this low-cost inertial guidance system program, has in fact been able to do many trade-off studies, trade-off of

reliability versus cost, trade-off of maintainability versus cost, trade-off of test calibration frequency in the field versus cost, trade-off of various types of support equipment, the complexity of it. These factors all model into it. The only point that I was making in terms of simplicity of model is that I have been able to program these things onto an SR-52. Something like 150 program steps or fewer, except for the two statistics. Except for those, it's a very easy model to work with. It allows me to make very rapid trade-off studies. On the front end of the program, our primary involvement is to try and get cost information back to the designer so that he can make an economic decision, which way should he pursue. Should he go with fault identification down to a certain level, what's it going to cost them, and what's he going to save and what are the cost consequences if he doesn't. How should he package his electronics. It's those type of design decisions that we feed back or cost decisions that we feed back that will influence the design.

BRANN-LITTON: I agree. My point was I just don't see what else would be necessary after that. All

the other refinements that would go into a much larger model, I'm not sure who would use them. Unless you are suggesting that a total life cycle cost model with everything in it would be used as budgetary by somebody for planning a program, and I would think that's kind of unusual since nobody has all the money for a program at the beginning. And a lot of the things in a model go in so many different agencies that effectively, I'm not sure who would want to know that one number for a total program, but by the time you got through breaking it into the segments that would care, you don't need that kind of sophistication in my opinion. I very much agree with you. I think when you're all done doing that, that's probably the end of the usefulness of the life cycle cost model, except for separate sections of it like generating spheres, quantites and so forth later on. Revisit it as you get experience.

(?) : Back to your question before, Al, where you asked if there are studies that are subtle. That kind of goes back to the first topic we brought up. I've had in my experience many times where the dollar value between alternative A and B is very small and you need to make sure that you consider everything that's

applicable. For example, did studies trying to decide whether you should have a large module or divide it in half and make two smaller modules, pretty far down in design. The cost differences there were very subtle.

(?): I think what you are saying is what is the cost effectiveness of the cost effective model.

GIBSON-ROCKWEL: That's it exactly. And if you're trading off between 90% built-in test and 75%, I think the differences are very subtle. Maybe that's not applicable trade, I don't know. There was a comment in the back earlier. Has it disappeared?

Onto the next one, then. Thank you, Bill. Appreciate that very much. The next presentation is on the same subject, with just a little bit different viewpoint. This presentation is by Bob Hurst, who works here at AGMC as Director of Plans and Programs. He's the program analysis officer and responsible for acquisition program management. Bob, would you like to give us your opinion on this subject.

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TOPIC: LOGISTICS SUPPORT COST ANALYSIS PRIOR TO FULL SCALE DEVELOPMENT.

DISCUSSION: LIFE CYCLE COSTING ACTIVITIES ARE USUALLY ACCOMPLISHED AFTER A DESIGN IS FIRM. THIS CAUSES CORRECTION OF PROBLEMS TO BE COSTLY IF NOT IMPOSSIBLE. LIFE CYCLE COSTS SHOULD BE IDENTIFIED EARLY IN ORDER TO SUPPORT LOGISTICS DECISIONS IN THE CONCEPTUAL PHASE OF A PROGRAM.

LESSONS LEARNED: IT IS FEASIBLE TO PERFORM A DETAILED ANALYSIS ON CONCEPTUAL DESIGN.

SPECIFIC LOGISTICS TRADE-OFFS CAN BE IDENTIFIED. DESIGN IS INFLUENCED AS A RESULT.

PROVIDES REQUIRED DATA BASE FOR LIFE OF PROGRAM.

REQUIRES A COMPETENT KNOWLEDGEABLE TEAM ENCOMPASSING SEVERAL DISCIPLINES.

RESOURCES ARE REQUIRED FROM BEGINNING OF CONCEPT.

HURST-AGMC: Logistics support cost analysis, LCC whatever you want to call it, I think the point we would like to make is that normally when you get down and define what life cycle costs are, you're pretty far into the program. The design is usually locked in concrete, you can't have much of an impact on changes because they become very expensive to accomplish and in some cases are never accomplished because the expense is too great to put changes in. We recently completed, a group of us, a logistics support cost analysis on some subsystems and a major weapon system coming down the road. And we found that we could get in during the conceptual phase and utilizing the right kinds of people and the right kinds of techniques, we could pretty well define, pretty accurately define what the logistic support costs for a major subsystem or a major weapon system could be.

The lessons learned are relatively simple. The first of them is that it is feasible to perform a

detailed analysis on a conceptual design provided you get the right people and dig into the depth that's necessary to make the analysis. Specific logistics trade-offs can be identified during this analysis and those logistics trade-offs can define changes that are necessary to make the system economically supportable.

We also find that it provides a very much needed data base for the life of the program. A data base that can be updated and be added or changed as new things occur during the life of the program, both in the conceptual design and even into the development phase. It can even cause changes into the deployment stages of the system.

What we found is that it does require a very competent team with several disciplines. In our case, we had depot people, we had the SMIM type people, and we utilized some contractor people in building the model that we put together -- not model, but rather the analysis that we put together.

One of the final points I would like to make and I guess I'm looking to people like ALD and the people that get in early in this program, perhaps even the (?) or whoever is procuring the system, there has to be resources made available early in the program

at the beginning of the concept, these resources in the form of money to perform these kind of studies are necessary and should be made available and I believe will end up saving many times the cost that you put aside for this purpose into the logistics support of the program. With that, are there any questions?

GIBSON-ROCKWELL: Bob spent a good hour or so on Tuesday in our Task Group describing the model and the detail that they went through in their analysis and I kind of sensed from that andthe discussion here that would you consider your approach complex versus Bill's simplified.

*HURST-AGMC: I would consider* our's complex, really. Actually it's not so much the model that's important, but the ability to dig into the design and find out exactly what it consists of. Break it down to its primary elements and when you do that you get to a point where you find out that there's nothing really new under the sun. It's all been invented before, it's all been done before, and there exists somewhere within the government or industry some basic data that you can apply to it and come up with a very reasonable and accurate cost.

GIBSON-ROCKWELL: Thank you, Bob. You know working here at AGMC, Bob has seen many of the marvels

of modern technology, but he says one of the greatest marvels to him is that we've developed a soda can that when you throw it away it seems to last forever, but we have $7,000 automobiles and you take care of them, they rust out in two or three years.

We've had a Task Group going for four or five years from this organization on life cycle costing and the chairman for the last year has been Robert Adel. On Tuesday, we thought he did such a great job, we voted him in for another year. We'd like to hear from him now continuing this same subject a little bit further and life cycle cost modeling flexibility and so forth. Bob is an IOS specialist for Northrop Electronics, responsible for life cycle costing and RIW analysis. Bob.

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TOPIC: LCC FORMAT/MODEL FLEXIBILITY

DISCUSSION: THE LCC TASK FORCE HAS WRITTEN A LCC MODEL CALLED CRIER. ALL REQUIREMENTS FOR INPUTS WERE ACCEPTED IN THE CONSTRUCTION OF THE MODEL, AND AS A RESULT, CRIER IS LARGE, SOMEWHAT CUMBERSOME, AND CONSIDERED BY SOME TO BE DIFFICULT TO USE. THOUGH INTENDED AS A "STANDARD" IT MAY BE MORE USEFUL AS A BASELINE FROM WHICH SIMPLE MODELS CAN BE GENERATED FOR SPECIFIC APPLICATIONS.

LESSONS LEARNED: (1) IF LCC IS TO BE EFFECTIVE, THE MODEL USED TO ANALYZE THESE COSTS MUST BE WRITTEN, ADAPTED OR MODIFIED TO FIT THE PROGRAM

AND HARDWARE TO BE DESCRIBED. THERE CAN BE NO "STANDARD MODEL." KEEP LCC FLEXIBLE.

(2) A MODEL THAT CAN BE USED TO ADEQUATELY ANALYZE AN INERTIAL SYSTEM IS READILY ADAPTABLE FOR AN ELECTRONIC/AVIONIC SUB-SYSTEM.

ADEL-NORTHROP: I'm going to talk for a moment or two about the formating that we can use for life cycle cost and flexibility of the models we use, which is merely a continuation of what we've already been talking about this morning. If you'll glance at that, we'll get into a little bit more discussion.

The two lessons learned regarding all of this is in my opinion I want to keep life cycle costs flexible and I think that when you write a model for inertial systems, you can use that model for nearly any kind of avionics or electronic equipment without getting in too much trouble.

The life cycle cost Task Group that's associated with this Joint Services Data Exchange, began writing a model in about early 1974. The model is called CRIER, which stands for cost reduction is everyone's responsibility.

The members of this group represent the entire inertial community. The group is made up of representatives from the contractors, like me, from the academic and research organizations and from the government. The initial step towards creating our CRIER model was to

identify the requirments. As each individual expressed what he felt were his needs, it became pretty obvious that it was going to be pretty darn difficult to include all of these needs from all of these people in a single model and keep it simple.

Each organization apparently has goals that are different than other people and if they were going to use their model as a significant and useful analytical technique, we had to include all of those needs. As a result, the model became complex and rather large and I've had many comments that it's extremely difficult to use. That's a consideration.

Our goal was to write a standard model and it was supposed to be a standard for inertial systems. I don't know that we really ever accomplished that. It was clear to me at least that it was difficult to write a single simple model that would cover all possible situations and this model became to me like a baseline from which simpler models could be created for specific uses.

Let's suppose that CRIER has checked out as a good model and we know that it functions and we know that it will do our job. And here it sits now. An individual, say a program manager, from a (?), say's I need to have

a life cycle cost analysis to support my program. Now let's take this complex model and from it let's throw out the areas that we don't need, reduce the sizes to something manageable for our program and include constants in there that are susceptible to our program, reduce the dozens of equations to possibly three or four or five and create a simple model that when you want to prove that it's a reasonable analysis, we have correlation to 95 or 98% to this huge, massive model here.

That can be done and I think CRIER might be an excellent baseline to create something like that. And in that case, why I would say that the lessons I've learned from that is that life cycle cost analysis should be kept flexible so that the analysis technique is useful for the purpose intended. In the previous discussions, if we are flexible, we can make that analytical tool useful for whatever purpose that particular program is.

And secondly, if we've created that baseline model, we need not restrict it only to inertial hardware, we can put it into any avionics type or electronics hardware and still have a good LCC analysis. Are there any questions, comments, arguments?

McDONOUGH-DRC: I'd like to offer this as sort

of a short commercial and we have done this. We have taken the CRIER model and we have modified it slightly. We've made it smaller, more flexible. I should say we have not made it more flexible, used the flexibiltiy that's there and we are using it. We've done sensitivity analysis with it, we've determined relative life cycle costs as I spoke about earlier and the model works, it works on several different computers. We've found it to be extremely efficient as far as computer time and it seems to perform as advertised.

GIBSON-ROCKWELL: Are there any other questions about the Task Group activity or anything?

I'd just like to comment that one lesson I learned from that is that apparently you can't take a complex model and make it simple for the user by good input sheets and good instructions. No matter how simple it is for the user to use, it is still looked at as a complex model and it scares everybody. To make a model simple, that model has actually got to be simple and something that one can easily follow through.

BEATON-DRAPER: The only comment I have is I've found it useful as a check list.

ADEL-NORTHROP: It's a rather encompassing model and as stated before can be used to predict

spares later on downstream, if that becomes a problem to you. If you're capable of estimating what you think those needs will be, which I defy you to do. You can use the model for escalation of costs and you can even discount the present value if you really wanted to, but I can't imagine what value that would be to anybody. But you can have at it, if you want to try.

Questions, comments? We do have a good life cycle cost Task Group, by the way, associated with the Joint Services Data Exchange and if you're not familiar with it, any of us would be delighted to inform you, put you on our mailing list and invite you to join us.

GIBSON-ROCKWELL: Thank you, Bob. Go right into the next chart. These two topics on software were submitted by Freda Kurtz from the Air Force Avionics Lab in Dayton. Unfortunately Freda called me the other morning and says she was indispensible and couldn't out out of Dayton. So I'm going to just briefly throw them out for discussion. I probably will not make the same points that she had in mind but I think there's some significant things here to mention and I would very much like to hear you guys' opinion on the subject.

TOPIC: SOFTWARE COSTS INCREASING

DISCUSSION: SOFTWARE IS BECOMING AN INCREASING PROPORTION OF THE TOTAL COST OF MOST AIR FORCE AVIONICS SYSTEMS. SOFTWARE HAS TRADITIONALLY BEEN IGNORED IN MANY SYSTEMS COST ESTIMATES.

LESSONS LEARNED: SOFTWARE IS SO SIGNIFICANT A PERCENTAGE OF TOTAL SYSTEM COSTS FOR AVIONICS THAT IT CANNOT LOGICALLY BE OMITTED.

GIBSON-ROCKWELL: Her first chart pointed out that the cost of software is significant and we'd better consider them. Now, many of us have ignored them in the past because they are hard to get a handle on for some reason. I don't really argue with Freda in the fact that we should be looking at them and considering them.

My question is though, and if you'll excuse the handwritten chart, I did it since I found out Freda wasn't going to be here, which cost should we consider, is the question I'd like to throw out.

Very grossly looking at the three typical categories that we address in life cycle costs, the R&D, production and O&F.

In the R&D phase, we have the software cost where we're developing the software and debugging it and getting it working. And theoretically when you go into production, you've got your software like your hardware designed is finished and over with; all

you've got to do is build it.

Now, I want to stress the point that I'm talking about avionic systems now. Maybe there are other things that this doesn't apply.

Then when you go into production, you've got typical sustained engineering costs of assisting the plant to get the hardware out of the door. Now, I crossed that out as a consideration in life cycle costs only because, in my experience at least, typically we include all of the sustained engineering as amortized into the hardware costs at this point. So we have engineers on the floor helping get the thing out the door, they work software just as well as they work hardware. So I crossed that off the list.

Then when you go into the O&S phase, it's my opinion again that the costs we see there from software come about because of changes that are required. Now I crossed this off the list because in typical life cycle cost studies, we're looking at specific alternatives assuming that that alternative is going to meet the requirements of the customers. In most of my studies, unless there's a particular reason that we're concerned about changes, we do not include those changes as cost considerations.

So my lesson learned and the main reason I

want to bring it out is to see if you guys agree with me, is that, yes, we have software costs in the O&S phase in real life, but they come about by changes and we have hardware changes -- hardware costs in real life that come about by changes. We ignore those in typical life cycle cost studies. What kind of response do I get from that? Everybody sits quiet.

ZIGONI-HOLLOMAN: I am not in the life cycle cost area, but generally, I would say if you are talking an inertial navigated by itself, I would agree. But if you're talking about an aided system, the cost of the operational test, improving it becomes a very significant cost and we must include it in the life cycle cost.

GIBSON-ROCKWELL: Back in the R&D section, before we're in production?

ZIGONI-HOLLOMAN: Both there and also in the operational support section.

GIBSON-ROCKWELL: Could you elaborate a little bit more --

ZIGONI-HOLLOMAN: I could do it very simply by saying the B-1 avionics, I hate to say this, the B-1 avionics came in for a six-month test program. It was primarily a software effort, not hardware. It took two years.

O'NEAL-ROCKWELL: When you're conceptually designing an auto navigator, there are a number of decisions that need to be made to decide whether you're going to mechanize your system in the hardware or in the software. I don't see how you can ignore the cost of changes because that's where software is supposed to pay off, so it's easier to change those holes than it is to go out and obsolete a bunch of hardware and put in new. I don't see how you can do those trade-offs right unless you model on into and try to somehow estimate the changes in the operational phases.

GIBSON-ROCKWELL: I think that's one of those categories where you are trading off changes. That's a very good point. Thank you, Don.

QUALLS-ASD: In my recent experience on the FQ program, as we take a briefing forward to the DOD level, we're being asked to supply increasing amounts of data on software that relate to life cycle costs. And in particular, one apsect that we're asked to provide data on is the trade-off between (?) memory or core memory and if you don't run the software changes out into the life cycle costs, how do you evaluate or trade this item off in the design phase?

(?) -SINGER: I'd like to know how does the CRIER model treat the software?

GIBSON-ROCKWELL: I think the CRIER model addresses it just as I presented up here, we treat it in the R&D as development cost, but after that it's ignored.

PETRY-AGMC: I've got a couple points to make. Since software is a recognized high-cost item, I think it should be included. The only thing is I've never seen anyone break it away from hardware and isolate it as a specific cost. We've been trying to get a handle on software costs for a long time, for all kinds of comparison purposes. But no one, including the contractor, is willing to separate it out, probably because it is such a high-cost item.

GOLDSTIEN-SINGER: The primary driving force for the entire area of high (?) is obviously towards trying to do software costs so I think it obvious that software must be included. DOD, Air Force, Navy, everybody is driving industry towards the (?) Precisely to reduce the software costs, supposedly since it will help.

ADEL-NORTHROP: I hate to give commercials to other companies, but I would like to offer some information to those of you who are interested in desires of identifying or formulating, estimating software costs. There are two companies and two

organizations that I know of that have written models and have methods for estimating software costs and/or operating support costs to support that software.

One model is called Price S. It's similar to Price, which is an RCA product and it's a pretty good model, I understand for estimating software costs, including the maintenance of software.

LOGUS-ASD: Is V&V in that, verification and validation?

ADEL-NORTHRUP: Yes, it's supposed to be there For you at AGMC, you specifically asked that question, I might ask you to contact Freda Kurtz from Wright-Pat from the Avionics Lab at Wright-Pat and she's been investigating Price S and she might be able to provide you with some specific information. I'd also like to usurp some of the people I see back there from TRW and tell you that a gentleman named Dr.Eldred Nelson, from TRW in Redondo Beach has written a model and done some extensive investigation regarding estimating software costs and I suspect if you contact him, you might get some useful information.

GIBSON-ROCKWELL: Thank you, Bob. That was the subject of Freda's second chart. But before I get

on to that, we want to back to the O&S phase for just a moment. I got the consensus from the group that O&S costs deal with changes and they should be considered. Is there any smarts out here as to how we should estimate the number of changes that are going to occur over the life of the program, any assistance that we can get in that regard. Or how should we consider it? Everybody's quiet. Don.

QUALLS-ASD: One method I've seen used on estimating the number of changes is just taking historical data that we have on programs and they look at it as about average of three changes per year. But this is for weapon delivery type of system and I'm not sure those numbers would hold for a navigator.

GIBSON-ROCKWELL: As a contractor, we're always afraid to go forth and show change in life cycle costs because then the customers says, gee, you guys are not very confident, you don't even think you're designing it right to start with. Don.

O'NEAL-ROCKWELL: On the Minuteman program we use a major update a year.

GIBSON-ROCKWELL: Okay. Good ground rule. Any other comments?

BRANN-LITTON: I don't think in inertial equipment in most cases that the change in the operational phase

to the inertial software,you know, the alignment software and navigation equations is very significant. But changes to automatic test equipment for fault diagnostic at the intermediate level andthe depot, has historically cost a lot of money and I don't think anybody disagrees. At the intertial portion of it, or prime hardware, there are changes, yes, but they're minimal, they might be done once a year and they're not too significant, but when you get into the automatic test equipment arena, historically that has been a problem for all avionics and has been expensive and what's normally been done, I think, is the model has underestimated the non-recurring software cost initially. I don't know that the recurring has been expensive, it's just the non-recurring that's usually stretched out a year or two more than it was supposed to has been a very significant cost element.

GIBSON-ROCKWELL: Thank you very much. I understand that the coffee is ready out there and it's a good time to take a break. Be back in about 15 minutes.

(Cofee break taken.)

GIBSON-ROCKWELL: So you know where you are in the program, we've skipped a couple along the way and we are now down on the one which says Statistics for Determinig Spares Sufficiency. Bill.

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TOPIC: STATISTIC FOR DETERMINING SPARES SUFFICIENCY

DISCUSSION: MANY LCC MODELS USE THE POISSON DISTRIBUTION FOR ESTIMATING QUANTITIES OF SPARES TO BE PROVIDED. THE POISSON IS AN APPROXIMATION OF THE NEGATIVE BINOMIAL AND WITHIN LIMITS IS USEABLE. HOWEVER, WHEN THE EXPECTED NUMBER OF FAILURES FOR WHICH THE SPARES ARE BEING PROVIDED BECOMES LARGE, THE ACCUMULATED ERROR MAY NOT BE TOLERABLE AND ONE SHOULD CHANGE TO THE NEGATIVE BINOMIAL.

LESSONS LEARNED: USE OF THE POISSON STATISTIC CAN RESULT IN SERIOUS UNDERSPARING WITH A CONSEQUENTIAL DECREASE IN OPERATIONS READINESS, AND AN OPTIMISTIC FORECAST OF LCC. COMPUTERIZED MODELS SHOULD EMPLOY THE NEGATIVE BINOMIAL STATISTIC FOR SPARES SUFFICIENCY CALCULATIONS.

BEATON-DRAPER: To get back to your introductory, Beaton is a Scottish name, not Irish.

This particular lesson learned is really one of a cautionary nature and the many life cycle cost models that I've looked at, they use the poisson distribution as an approximation of the binomial in determining their spares sufficiency. I found out on the particular program I'm working on, at least with the numbers that we're generating, the failure rates that we're using, that you can come up with a significant difference between what you would project for need of spares and costs, when you compare it with more exact statitstic which happens to be the binomial distribution.

All I've done is plotted the two statistics and there's nothing earth-shattering here, it's strictly

one of warning that in using a life cycle cost model and if it does in fact use the poisson distribution for spare sufficiency, that you be aware of the limitations of it because it's only applicable when you have high reliability or low failure rate items. As your reliability decreases, then you get a divergence between the two curves.

I'll show you thesignificance of it in the next chart. I've taken those same values that were plotted on the graph and there's a function of expected failures per year and I'm talking about a 90% spare sufficiency requirment for 200 systems. And what we've got is the poisson distribution gives me one set of numbers where the spare sufficiency probability, I've chosen to use the negative binomial, you can also use the binomial distribution, but for some strange reason I haven't been able to find out, the negative binomial is much faster and doesn't saturate an SR-52, whereas the binomial does. So I calculated the spares needsand the spares -- of the probability of being out of spares for the two distributions and where it becomes significant is either you wind up with less spares, which means you've got a lower cost projection if you use the poisson. If operational readiness is a prime requirement, requirement

of the program you're working on, then you are going to miss it by miles, if you spare according to the poisson and you have with the qualifier that you've got a high failure rate item, because if you take a look at the last number, if I've got an expected 74 failures or 75 failures per year out of 200 and I go over and look at that error column, I'm short 19 spares over what I should be sparing. In fact, my spare sufficiency is 39% as opposed to the 90% that the poisson will give you.

GIBSON-ROCKWELL : Bill, how do we know which distribution really tells us what the real life situation is going to be?

BEATON-DRAPER: Well, it all depends on how accurately you've picked your expected failures. I mean the statistics are --

GIBSON-ROCKWELL: What I'm saying is, if we go out and look at demands on a specific inventory in real life, do those demands occur with the distribution that we define mathematically as a poisson distribution or binomial or neither one?

BEATON-DRAPER: Well, what you are looking for when you apply spare sufficiency statistic is what's the probability that out of a population of, we'll say,

N plus C, that any of them will work at any time and that's in your spare according to that type of statistic. The binomial is the more exact statistic to use. That's the only point I'm making. You either have a choice of the poisson or you have a choice of the binomial. While I'm not saying you can't use the poisson, if the model has that as a distribution, it is using that statistic, then it should also have some qualifying statements in there that you be careful of it in the event of a high failure rate item.

ADEL-NORTHROP: I have two or three questions to ask you, Bill. First question would be, we have a technique in CRIER of determining spare sufficiency by using a product of probabilities, which says that if I want a spare sufficiency of 90%, then what I'm going to model is, if I go to that stockroom to select a spare of any one of those dozen or two dozen modules, whatever I decide to put in that stockroom, I want a 90% probability of having a spare available to me regardless of what failed. Consequently, in order to compute that statistic,you identify each of the items you want to spare and you have a product of probabilities. I want to know if you took that into account and secondly,

model and as stated before can be used to predict



if you think that's a good modeling technique.

BEATON-DRAPER: To answer your second question first, I don't think it's a good modeling technique for the reason being what you wind up with then is a probability -- let's see if I can phrase it properly -- if you have a 90% requirement and you did as you suggested, come up with a product of probability that would give you 90%, then you'd wind up with a probability that 90% of the time you would never be below 90% spares level or some such thing as that. Maybe there's a statistician in here that can say it a little more clearly. But when you calculate your spares requirement, you have an inventory of parts and if somebody says I want 90% assurance that I will have a spare of a given type, then your model doesn't have to product all of those individual probabilities. All you're concerned with is the probability of a given type of hardware or a given type of spare being there at a 90% assurance level.

ADEL-NORTHROP: That's for each item. Okay, fine. Thank you for the answer. I want to ask another question. What you have done in either of those probabilities, in either of those distributions, is stock spares based on the probability of stock out. That's what that does.

You've just used two different distributions to describe your stock out probability. And that's okay. I'd like to know if you have evaluated spares based on availability of hardware. That doesn't address availability, that only addresses the probability of stock out. What is your concern regarding availability?

BEATON-DRAPER: Well, if you're talking about availability, you're talking about a term that's defined in the textbooks as being a ratio of your up time to the total time of exposure of a piece of equipment and if I was to apply a sparing philosophy to that, your down time is measured in terms of several factors; one being failures, how frequently items fail that require the thing to be down for repair. Another might be down time as a result of the necessity to calibrate a piece of equipment, which may or may not result in having a spare. Another might be down for diagnostic testing because of some (?) that was seen on a readout, which again may not require a spare. But if you have a high operational readiness requirement, the operational readiness is a product of availability and the probability of having a spare to fix the situation that's resulted in the down time.

Then you would have to spare on the basis of

your hardware designed is finished and over with; all



not only the failures that you anticipate, but also spare on the basis of calibration intervals and also any unexpected false alarms or (?) of that nature. It's either that or else you accept a lower operational readiness because you're down to other factors than those that would require that you replace hardware. Did I confuse you or did I answer your question?

GIBSON-ROCKWELL: Other comments on the subject? Experience? Questions?

NEIWOOD-SINGER: I'd like to hear that definition again of readiness versus availability. I didn't quite understand that.

BEATON-DRAPER: Operational readiness is a product of availability which is a percentage of up time or down time, however you want to look at it. And the probability of having the spare available. In other words, you are operationally ready when you are able to fix something that's down if you can get up in a certain time period. If, for example, you've got a piece of equipment that's down, for simplicity's sake, let's say it's a hardware failure, and it takes you one hour out of ten, ten hours available that equipment has to be on the air one out of ten of those hours that it's down, then you've got a 90% availability

of equipment. Now, the operational readiness would then depend on your having the spare item or a spare system or whatever to replace that with. That's where that 90% spare sufficiency probability comes into play, because if I've got a 90 percent chance that I'm going to be down 10% of the time and 90% of the time I've got a spare to fix that thing, then my operational readiness would then be the product of the two, would be 81%. Up 90% of the time, got 90% assurance that I can have a spare there,so the operational readiness would be 81%. These are textbook definitions, not mine. I think if we are going to deal with subjects of this nature, we have to stick with terms that have been defined and accepted. If you're going to establish a new term, then they should be defined, but not with the same meanings as standard ones.

HAMMON-FTD: I again raise my point as to cost per spare once those spares are not being manufactured on the production line but have to go back to the manufacturer and start up production line in order to manufacture those spares. At that time that cost of the spare has a legitimate cost to the manufacturer,is a factor of ten greater than what it was before.

BEATON-DRAPER: I won't dispute that. When you contracted to perform a task, there are usually some

ground rules that are established to allow you to perform that task, and in the case of this particular program that I'm working on, the ground rules were that we would do our life cycle cost estimates on the basis of $76. Now, I agree with you that five years from now the cost may be higher or lower depending on the economy and inflation, advancement of technology, but in my model it does not account for it. There are models that do account for inflationary factors. I think that's not the question that you're posing. You're posing one that's more catastrophic in the effect that even if three or four or five years from now we require spares and the supplier is no longer providing them for you, then what do you do? I don't have an answer to your question.

COLE-NAVAIR: What he's bringing up down there about the spare situation, this is totally a government function, because the government plans on a program for X number of years using aircraft or whatever. If they run over that, that's their problem. They should plan for a 30-year program, if that's what they want to operate under. If you plan a 20-year program and the 20 years are up and the manufacturer is out of business or his line has been shut down and you can't get spares, that function, I don't believe, can be figured in in an

overall program. That's beyond the scope of the original program.

BEATON-DRAPER: Dave was making a point earlier that there's a DOD requirement that you can't spare beyond longer than three years in advance of a given program. You're shaking your head no. I don't want to get in the middle of that debate, because I wasn't there at that time.

GIBSON-ROCKWELL: The thing we are talking about here anyhow is the prediction of your spares lay-in. What spares quantities do you need to fill your pipeline and your inventory, which is done initially generally, and the problem that comes up with increased cost is when you then have to replace consummable or damaged items, condemnation items later. This is dealing with the initial acquisition.

BEATON-DRAPER: It's strictly a point of caution, is all I'm bringing out, is just be careful which statistic you do use because the poisson is limited.

GIBSON-ROCKWELL: We probably ought to be moving on to the next subject, which is to be presented by Jim Taylor of Honeywell. The topic is dealing with the age-old problem that life cycle cost analysts have and that is where do they get the data to go in the model because it's data

that they're not responsible for. Jim works for Honeywell as a senior maintainability engineer and life cycle cost specialist in their avionics division. Jim is one of the pioneers in the Task Group. He's been with it since its conception and he just recently completed his two-year tour of duty on the Executive Board of that group. Jim.

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<u>TOPIC:</u> COST/TIME STANDARDS FOR USE IN LCC STUDIES

<u>DISCUSSION:</u> REQUEST FOR PROPOSALS (RFPs) FROM DIFFERENT PROCURING AGENCIES CONTAIN DIFFERENT COST/TIME STANDARDS FOR USE IN LCC STUDIES. SOMETIMES STANDARDS ARE NOT SPECIFIED AT ALL. COST/TIME STANDARDS INCLUDE SUCH QUANTITIES AS REPAIR TURNAROUND TIME, TRANSPORTATION COST INCLUDING PREPARATION FOR SHIPPING, RATIO OF PACKAGED WEIGHT TO UNPACKAGED WEIGHT FOR BOTH OVERSEAS AND CONUS, MILITARY LABOR RATES, INVENTORY MANAGEMENT COST, FACILITIES COSTS PER SQUARE FEET, AND MANY OTHERS. A CURRENT APPROVED LIST OF MILITARY COST/TIME STANDARDS IS NOT AVAILABLE.

<u>LESSONS LEARNED:</u> (1) COST/TIME STANDARDS MUST BE PROVIDED BY THE GOVERNMENT WHERE LCC REQUIREMENTS ARE SPECIFIED.
(2) A CURRENT LIST OF COST/TIME STANDARDS MUST BE DEVELOPED AND MAINTAINED BY THE GOVERNMENT - AT LEAST FOR EACH BRANCH OF THE MILITARY.

TAYLOR-HONEYWELL: Thank you, Keith. First of all before I get into this, I'd like to point out as a member of the Joint Services Data Exchange Life Cycle Cost Task Group over a period of about three years, I've sent out surveys to both the industry and government trying to determine the list of standards and time factors that we currently have in the CRIER model and for those

you that would like to havea copy of that, I have it available. I personally don't believe that we'll ever come up with any kind of cost standards for even various types of equipment because within various agencies at Wright-Pat or Egland  I have looked over numerous cost time standards and they all differ, so we urgently need cost time standards. And from a contractors' standpoint, if they specify training, for instance, do we as contractors, include the transportation costs for the personnel attending the courses. Do we also include the per diem rate. If you do, you may earn a little credibility and get a higher technical score, but on the other hand, you're increasing your costs. This is one example; there are many.

Others are labor rates. The labor rates within -- even within the Air Force, between one agency and another, they vary significantly. They are far from being real.

So some of the lessons we've learned is as I stated earlier, I don't think we'll ever have any cost standards that are identical that we could use for a specific type hardware and I think it's incumbent upon the government or the procuring activity to specify

what these cost time standards might be, including turn-around time or depot level, intermediate maintenance and transportation costs, preparation for shipping and that sort of thing. I think this list of standards should be provided to the contractor and I think the contractor should respond to specifically what is specified in types, in terms of standards and cost/time factors in order to be competitive. Otherwise, he's shooting himself down, in economy.

GIBSON-ROCKWELL: Anybody have some real good experience they may have had in getting these factors to use?

BEATON-DRAPER: The only comment I have is that any such standard list is subject to continual changes as a result of inflationary characteristics. You're either going to have to provide a factor to allow for that or just base it on the rates that exist at that particular time. Do you have any ideas at all on how this thing should be established, how it should be formated?

TAYLOR-HONEYWELL: Appreciate that comment. I have some ideas. I don't know how you would ever implement them, but I think that by types of equipment, for instance inertial navigation systems, you ought to establish a

turn-around time, transportation time, preparation for shipping time, the ratio of packaged weight to unpackaged weight. The ratio of cost for maintenance of age and the spares for age to the acquisition cost or some other method. Because if you don't, if you have a dozen people bidding on a given INS, then the people that are doing the source selection on this item may be using different figures entirely and since they're not provided, it leaves the contractor at a handicap, as well as the source selection committee is at a handicap because they have to do a lot of work themselves in order to come up with what they consider to be credible figures.

LAWRENCE-LITTON: I can say amen to that. We have a program going at the present time related to this, the (?) program, which is of a similar nature to the life cycle cost, includes many or most of the same cost factors. We have a bit of a problem here in the fact that we are doing an (?) on our black box that goes in an overall system in conjunction with MACAIR, (?) on the systems integrater who is doing the overall cost on the whole thing and they in turn have to interface with Boeing, who is doing the overall cost on the missile. And we have been unable

to get a lot of these factors and when we try to correlate our (?) with life cycle cost, if you wish, with other programs related to it, just as you said a while ago, we just plain don't have correlation. And we have got down on our hands and knees and begged for numbers and, the same thing you said, nobody has numbers to give us. So we are having considerable problems trying to do an (?) and correlate with other related efforts.

HAMMON-FTD: General Rogers, in his briefing yesterday, alluded to the fact that many of the DOD technology repair centers are now needing to compete for who will be doing what repair. AGMC currently repairing some Navy inertial systems. The feeling that at some level decisions are being made at which repair center things are going to be done. Are the repair centers compiling costs to do that and submitting it to some joint logistic commander's committee for that decision. If so, would not that data be available at least a labor rate or something to the contractors as a basis for them to then estimate future systems, recognizing it wouldn't be necessarily the same one. Here's at least a data base.

(?) : I'm sure glad to hear you ask that question, because under the freedom of information

act, we should be able to get that information, but it is extremely hard to come by and I think that if you had the information, cost information available on various systems, you'd be able to establish credible ratios of cost. For instance, the cost of spares and maintenance for age, and that sort of thing. But it is rather hard to get information on cost of existing systems even 66-1 data. Or 3M data. It is the only thing that we have. If we had these summaries, then you would be able to dig out a certain amount of information as well. It's hard even from a procuring activity to get accurate deployment information, if they plan for a weapon system. It makes it extremely hard for us trying to perform where the analyst is trying to perform life cycle cost studies because many times he makes assumptions that don't fit the picture at all. So consequently your costs are not valid, based on the number of sites or secondary deployment, such as you'd have in SAC or so forth. I'm very glad you brought it up. I'd like to ask the gentleman over here, before I start, are you doing this (?) in accordance with 800-4?

LAWRENCE-LITTON: Yes, it is basically the formula we're using in our computer is one that is supplied to us from MACAIR on the F-15 program. Yes, it basically

follows that spec. There are slight differences, but they are very subtle.

TAYLOR-HONEYWELL: You do have standards in 800-4, which is the (?) and of course these are very old and invalid and you look at some of the late ones that even came out from Egland the other day, they even look older. You also have some standards in 375-7, which are also far out of date, to make a realistic cost picture.

PRICE-AGMC: Addressing the comment pertaining to cost figures, historical cost figures being available, they are available. It's extremely difficult, if not impossible, to make correlations even within the Air Force is the point you made. And part of this, of course, is being compounded by the conflicting information that is being handed down by DOD today upon costing. And I'll cite an example. AGMC, a couple years ago, like at the end of 1974, went into, what we refer to an actual hour costing system. We did away with standards. We're still using them, but as far as reporting cost, we are tying it right back to the man on the floor, direct labor cost he was punching in against the serial number. We're accumulating costs, rolling it up from the component right on up to the end item going out the door.

Just within the last six months now, Congress

has shot down and pulled funding from the ALC's who were going to convert to a similar type actual-hour accounting system. There's controversy right up at DOD level on whether or not we're going to use standard or actual-hour accounting. If the Air Force can't agree, how in the world can we ever hope to agree, you know, to the other services.

HAMMON-FTD: I'll set the record straight. I'm a reservist with FTD and a full-time employee at Battelle in Columbus, Ohio. So I'm here as a wolf in sheep's clothing or vice versa.

I appreciate that the Air Force has had trouble with Congress on the accounting system, but even still AGMC has had this underway for a period of time. The data exists. Why can't you release it? Yes, the other ALC's would like to do it and the Air Force would like to have it done, but got stopped by Congress, but you've got data, why can't that be released?

McDONOUGH-DRC: The only point I'd like to offer on using the actual accounting data is the somewhat lamentable fact that work expands to fill the time available. So you are going to find that everyone puts in 40 hours every week and it may not be the amount of time that might be required on a particular repair had

there been more systems to repair.

GIBSON-ROCKWELL: Jim, how about going on to your next subject?

TAYLOR-HONEYWELL: Could I respond just to this one just for a moment. I don't think if a man works two hours a week and the 66-1 data picks it up at 40, is really significant if that is what it is costing the Air Force, or the government. I think what is significant if various contractors or people within the industry could determine accurate costs on systems, possibly there is some way it could be cost effective to the government from the contractor's standpoint in doing studies to see whether the cost could be lower.

LOGUS-ASD: You bring up an interesting comment about whether it's two hours or 40 hours. This is one of the beefs we've had about life cycle cost analysis. It seems that most analysis treat the people as if they're hourly wages piece part, when in fact the they're salaried and we own them for a year. This is particularly true when we're talking about the field and where we have to man around the clock whether that -- and against not whether the normal rate, but against a war-time rate, which is usually three times higher or two and a half times higher. So this notion of doing, say, a life cycle cost analysis against a failure rate and assuming

that the guy is hourly, just can lead to some misleading information as far as how your doing in the field and total life cycle cost, in fact.

GIBSON-ROCKWELL: I was just going to say then you have to figure out where the division is between increments of men. You want to make your task just hard enough it takes the guy full time, but not any harder than it goes over to the second man.

QUALLS-ASD: Usually you'll find in the field shop you have -- and my background is I'm ex-enlisted in the con-nav field -- you'll find that you man to match up with your peak flying hours and at that peak flying hour rate, you have an expected probability that you will have X number of failures. You man your shops based on that number.

Another problem you'll find is that it's not a stationary type of thing. If you're in a TAC wing and you have deployed units, you also have demand to put a minimum number of technicians in deployed aircraft. So when you start figuring life cycle costs and you try to put in deployments and you say that I have to have specialized test equipment to maintain a squadron that's deployed, you know, a lot of these factors are left out right now. We realize that and when we supply you with

the data for a deployment and for our wage -- the type of data that the government supplies you -- we realize that. And we give you a more or less standard situation so that the people that are responding to our RFQ are at least using a consistent set of data. If the government agencies don't supply you that government data so that you are consistent, we are really doing you a disservice.

TAYLOR-HONEYWELL: Let me make just one fast comment on that. We in life cycle cost studies do consider an earned-hour ratio of say if you had 30 minutes active repair time, you must have a 4.5 hours expended for that to account for the logistics time and that sort of thing as an average. It varies depending on the level of maintenance. For instance, you might have an item come into the depot that cost 8 hours active repair time. By the time you do all the handling and the packaging and so forth, the cost is significant, probably cost you a week or more. We do take it into consideration then.

GIBSON-HONEYWELL: Thank you, Jim. Why don't you move into your second discussion then.

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TOPIC: RELATIONSHIP OF LCC TO REQUEST FOR PROPOSALS AND STATEMENTS OF WORK

DISCUSSION: MANY TIMES AN RFP OR SOW ALLUDES TO AN LCC REQUIREMENT WITHOUT ACTUALLY SPECIFYING AN LCC STUDY. A SOW QUOTE WHERE LCC WAS NOT SPECIFIED: "THE IMPACT OF SUPPORT ALTERNATIVES UPON SYSTEM/EQUIPMENT LIFE CYCLE COST, AVAILABILITY, EQUIPMENT AND MANPOWER LOADING AND STOCKING OF PARTS SHALL BE PREDICTED AND EVALUATED," LCC IS NOT MENTIONED ELSEWHERE IN THE SOW.

LESSONS LEARNED: WE AS LCC ANALYSTS HAVE A HARD TIME SELLING MANAGEMENT ON THE IMPORTANCE OF LCC, PARTICULARLY WHEN THE GOVERNMENT DOES NOT CLEARLY SPECIFY LCC REQUIREMENTS.

TAYLOR-HONEYWELL: I won't take much time on this except this is the relationship of the request for proposals and statements of work. I guess from the standpoint of life cycle costs both within government and industry, life cycle cost is certainly a buzzword. And we end up getting it mentioned in statements of work and RFP's without any deliverable documentation, without it being mentioned anywhere else in the proposals. I've seen this happen a number of times. So our management, I'm talking about me as an analyst, they won't permit me to perform a life cycle cost study because I am direct charge to the program. Consequently, it increases their cost. So I think it's incumbent upon the government to specifically state what their life cycle costs requirements are without alluding to them, and that's what I was trying to point out here. I think it's very important, because we might

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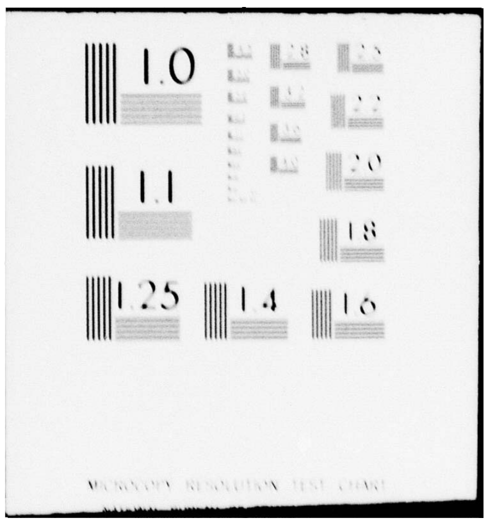
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ignore something that they wanted done because it's not cost effective.

GIBSON-ROCKWELL: Comments? Thank you very much. In excusing Jim, I just want to make one comment. He's become quite an avid golfer in the last few years. He took up the game of golf as doing his part to conserve energy. He says his golf cart uses less fuel than his lawnmower.

TAYLOR-HONEYWELL: On the CRIER users' manual, I have a limited number of copies left and those of you that would like to have them, if I don't run out, if you'll give me the address, I'll be glad to give them to you. It has a list of standards as well as how the model operates. I can't give them to you. I'll mail them to you.

GIBSON-ROCKWELL: The last subjects listed towards the bottom of your sheet deal with reliability aspects of life cycle costs and we had some real good sessions yesterday on reliability. I think it was people from Litton pointing out the importance the role that on/off cycles play in the reliability prediction and it was also pointed out the disparities between predictions and what we actually achieve in the field. I want to skip this topic of field reliability prediction, since

it was covered quite well yesterday. I want to bring up one more subject on this field versus -- MTBF versus operating hours situation.

We quite often in the life cycle cost world take a predicted MTBF and factor it by some K factor to get to what we envision or interpret to be a field MTBF. But then we go ahead and do our studies and bury the operating hours as to the sensitivity and so forth and we forget that maybe difference in operating hours will change the mean time between maintenance, in operating hours.

We heard some of this yesterday and I've asked Joe Kennedy to come to us today and relate some experiences he's had in this regard. Joe.

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TOPIC: FIELD MTBF VERSUS OPERATING HOURS

DISCUSSION: GENERALLY, LCC STUDIES USE PREDICTED FAILURE RATES FACTORED BY A CONSTANT (K) TO APPROXIMATE FIELD RELIABILITY. OPERATING HOURS ARE THEN OFTEN VARIED FOR SENSITIVITY STUDIES WITH NO FURTHER CONSIDERATION OF THE RELIABILITY APPLICABILITY.

LESSON LEARNED: OPERATING HOURS CANNOT BE ARBITRARILY CHANGED WITHOUT CONSIDERING THE RESULTANT EFFECT ON THE INPUT MTBF.

KENNEDY-AGMC: I am not a life cycle cost practitioner. Let's get that straight. So don't ask me any complicated questions.

These charts I'm going to show here come out of

kind of a discussion or argument I had with the item manager over the repair of items at AGMC the last few years. They are not too up to date. Keith thought you might be interested. This chart here is just a definition of those data elements that we collected at AGMC in its attempt to determine how effective our repair is. Now most people call those reliability indicators. I don't like the word, but they're both up there. There's (?) time, load time, they're up there. The time between overall is the one we use mostly at the depot because it's dependent upon the ETI meter and we can get that easily.

Now the one I want to talk about is the mean time between failure or in the logistics definition mean time between demand. This is what the item manager uses. Because it is out of a DO-41 program which is really a supply computation program. It's a program that tells the item manager that, okay, his flying hour program is going to increase the next quarter, this number should tell him just how many repairs he should have, spares he should have and all that kind of jazz.

On inertial systems, it's just about identical to MTBF that you might get out of 66-1, because there's no repair done on the aircraft on these systems.

And notice the equation. The way you get this is

you take the total flying hour program of the entire fleet for a period of time, say a month or a quarter. All the flying hours. And you divide that by the number that are removed from the aircraft. That says rejected. Most people say removal because (?) are not filtered out of that.

You can go one step further with that, they have an MTBO, which is the same equation except that deals with those that are returned to the depot.

Now, we at AGMC collect the MTBD numbers and show these; we actually get the numbers from the item manager, we don't collect the data. We do it more in self-defense, because the item manager, AFLC and most of the people in the Air Force environment use that number as a indicator of how effective our repair is. It's also used quite a bit, I've noticed, in different cost studies, trade-off studies, whether or not a system should be replaced. This is where it bothers me.

They'll use the MTBD of a fielded system, call it MTBF, and compare that against predicted MTBF of some contractor's prediction what he's going to get with the new system. One thing that this chart shows, and this is on the KT-73, and that shows it's not too recent, but the point I'm trying to bring out here is what we are

plotting here, the dash line is the flying hour program and the solid line is the MTBD. Note the correlation between the two. The flying hours go up, the MTBD goes up. The flying hours go down, the MTBD goes down. The number of removals from the aircraft tend to stay relatively constant.

Now, if you were doing a life cycle cost study, what point in time, depending on the point in time, you took the particular MTBD, you might drastically change your results,depending on the flying hours.

This is the same thing on the C-5A. You can see the same correlation exists there. There was a cost study on the C-5A program where they had decided to change the INS and this figure was used in it.

Here's the one that really started us off on this kick, it's on the LN-12. It's got a couple good points in it. If you notice way back in the beginning of the chart, back there in the middle of '73, the MTBD was up about 140 hours. It had been up in that area for quite some time. The flyer program was quite high during that period of time, too. That for the people who know the history of PRAM and prior to PRAM rivet gyro, was just about the time that the rivet gyro study related to the LN-12 was completed. The MTBD was about

140 hours. They predicted that it would go up to 200 hours, if all the improvements recommended by rivet gyro were put in. You see what happened in the next quarter it dropped from 140 hours to something like 90 hours.

Now, also what happened at the same time is the oil crisds. And the flying hour program just dropped in half and the MTBD went right with it.

In essence, correlation stays pretty good, fairly well, along the line. Again if you look at the removals for the aircraft they tend to stay relatively constant. So one point here I'm trying to get across is that I feel that MTBD as a number to evaluate repair effectiveness or evaluate quote reliability of the system stinks. Unless you have a constant flying hour program, constant environment, then the meaning of the number is too sensitive to any changes that are going on. It doesn't tell you anything about the hardware or about the repair effectiveness.

There's another little warning that came out of this one on the LN-12. You notice about here at the fourth quarter of calendar year '75, the MTBD number dropped way down below on this chart the flying hour program, but then picked up the correlation again. That period of time,

those two quarters that are plotted there, what happened in the reporting system is the removals from the aircraft; they can be divided into two parts. The removals that can be repaired in the field, what we call RTS's, repair this station; and the other part of it is the NRTS's, not repairable at this station are sent back to the depot.

During that quarter, and as a matter of fact throughout most of that period of time, the returns to the depot were relatively constant, regardless of what the flying hour program did. Something very strange happened in the reporting system. The number of systems that were reported to have been repaired in the field in a six-month period of time, went from something like 300 a month up to 800 a month, very rapidly. And there's nothing you can do in a program or in a repair depot that could cause that kind of change in the activity. I personally think, and we've been trying to blow this out of the system and DO-41 is a very complicated supply kind of thing and there's a lot of little items they have in there like if they order a system and there's not one available, then it kind of dings the system twice, and there might be something just in the computer that caused that. But either that or something changed

in the reporting requirement which has completely changed the number. I don't think it's valid even to compare this number from prior to calendar year '75 to calendar year '76.

This is sort of like a running discussion I'm having with Frank Squires. He kind of agrees; his problem is that he's hooked to the system, the whole AFLC logistic system is based upon DO-41. This is a very major contributor to DO-41. Of course, all the smart managers take the output and then put some kind of factor or finesse out of their earlier experience on it, so it doesn't get you into too much trouble.

NIEWOOD-SINGER: I have a comment and a question. My comment first is that your statement that 66-1 and the demand rate are the same hasn't been true in our experience. Even though it's an inertial system, somehow or other they manage to charge repairs against that inertial system on the flight line, and you'll find as many repairs or failures because they equate the two, charged on a flight line as are charged off the aircraft. They call them repairs. I didn't say they were actual repairs. There are calibrations that are performed on the aircraft that are counted as failures. There are broken screws and wires that are repaired

that are counted as failures against the inertial system and they all get tallied into the number. Consequently, about one-half of the MTBD or demands that you discussed, okay? Now, that's my comment.

My question is how do you account for the fact that there is a constant pull rate regardless of the flying hour time. Is this something that's akin to what was mentioned earlier that we will have the same maintenceman hours charged against that airplane regardless, because we have the same maintenance crew. How do you account for the fact that the pull rate is constant?

KENNEDY-AGMC: Let me answer your first one first. I probably said that in error. Believe it or not, AGMC does not use 66-1. I don't see 66-1 data. I really don't know what it is on the KT-73. On the LN-12, what I said is true, this is one we have looked into and the MTBD and MTBF for 66-1 are very close. Now, in 73, I'm not sure what's going on.

As far as why this occurs, why you have a constant failure rate and that has started a lot of different discussions, one idea was that well, what we first heard was what is happening is we are not flying as much, you got a lot of crews, there's nothing

to do, there's a lot of preventative maintenance that they've been wanting to do for years,and they went and did it. That appeared to happen on the LN-12 for about a month's period of time. But the other thing is TAC went into a program where they wanted to -- they had to reduce the flying hour program because of the oil, but they did it by reducing the length of the flight, not the number of the flights. The sorties stayed constant, they tried to fly two flights for every one before.

Now, most failure modes in inertial navigation systems are a function of turn on and turn off, not wear out. Very little wear out in this kind of numbers are based on a wear-out philosophy. Most of the repairs that we get are the systems we get back. It's not because they wore out. They just broke. And there's a real question whether that philosophy should apply.

That by the way is what started a lot of this conversation about turn on and turn off counters, and the effect of on/off cycling. Frank Squires' rebuttal to this -- I had to give him a chance -- he did a study in response to this. TAC has now since changed that philosophy. They have gone back to long flights, but not as many flights.

And he has done a study trying to correlate sorties with the MTBD and it kind of goes against the argument that I just gave. But honestly, I really don't know. All I know, and the only point I'm trying to make here is this is the correlation and just why does it occur is there is probably ten different opinions from ten different people. I personally think it's the on and off that has a lot to do with it.

GIBSON-ROCKWELL: I hate to do this, but the bus is out there ready to leave and Earl Bodem will be very upset if we come marching in late to lunch.

So I want to thank everybody. Appreciate it.

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